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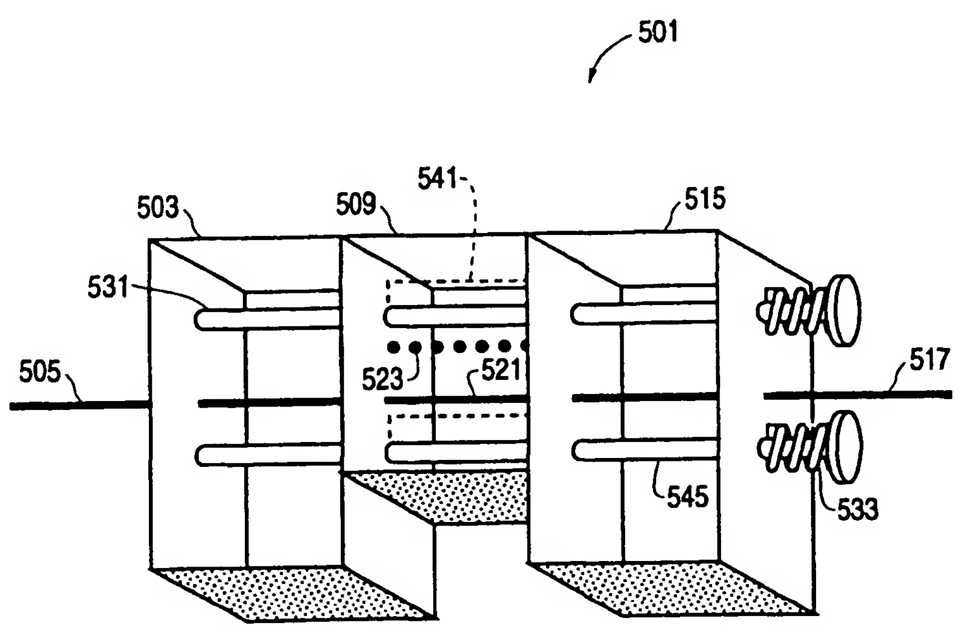


(57) Abstract: An opto-mechanical switch (501) includes a mechanism that selectively aligns a normal optical fiber between an input fiber (505) and an output fiber (517) in response to a control signal. The optical components of the wavelength switch comprises of input block (503), central block (509) and output block (515). The blocks have rods (531) and slots (541).

WO 02/23244 A1

OPTO-MECHANICAL SWITCH

FIELD OF THE INVENTION

The present invention relates generally to switching equipment for optical fiber communications systems.

BACKGROUND OF THE INVENTION

Optical fiber communications systems transmit many individual light signals through single optical fibers. Each of the individual signals traveling through an optical fiber has its own wavelength. The transmission of many optical individual signals each having a different frequency through a single optical fiber is known as "muxing" or "wavelength division multiplexing", WDM. Many optical fibers are connected to each other at optical nodes to form optical networks allowing information to be transmitted between the nodes.

Referring to Figure 1A, a simple "point to point" network includes two optical nodes 105 connected to the ends of an optical fiber 103 is illustrated. Electrical data signals are converted into light signals at a first node 105, transmitted through the optical fiber 103 and received at the second node 105. Light signals can currently travel a few hundred miles through an optical fiber 103 before the signal becomes too weak to identify. The light signals are received at the second node 105 and can be converted back into an electrical signal before being routed to a local destination.

Referring to Figures 1B and 1C, more complex optical networks can be constructed with nodes 105 that are connected to multiple optical fibers 103. Figure 1B illustrates a "ring" type network. Optical signals are transmitted from node 105 to

node 105 through the optical fiber 103. At the nodes 105 the optical signals may be amplified and/or switched to any of the other optical fibers 103 connected to the node 105. The circular configuration of the ring network allows signals to be transmitted between any two nodes 105 in the network even if there is a break in any single fiber 103. This redundancy of data transmission paths allows maintenance to be performed on components of the network without interrupting the operation of the rest of the network. Figure 1C illustrates a "mesh" type network which provides further redundancy of transmission paths as well as more direct optical paths between nodes 105. In complex networks, the optical signal may be switched at many nodes 105 in order to be sent to the proper destination. Where many individual signals are muxed in a single fiber and each of the individual signals has separate destinations, the individual signals must be separated and individually switched at the nodes.

There are two broad categories of optical switches: optical – electric – optical (OEO) switches and all optical switches. In OEO switches, the individual light signals are converted into electrical signals which are individually switched to their desired paths. The individual electrical signals are then converted into light signals that are muxed and retransmitted through another optical fiber. The OEO switches require complex and expensive equipment.

Referring to Figure 2, a reconfigurable optical add/drop multiplexer using an all optical switch system 201 is illustrated. A first group of muxed signals are transmitted through an input fiber 211 to a demuxing device 215. The demuxing device 215 separates the individual signals and transmits each individual signal through a dedicated optical fiber to signal switches 217. Each switch 217 directs the individual signal from the demuxing device 215 to either the muxing device 219 or

the "drop" signal fibers 221. For individual frequency signals that have been dropped, other signals having the same frequency may be added through "add" fibers 223 which are connected directly to each of the switches 217. The signals that are directed by the switches 217 to the remuxing device 219 are remuxed and retransmitted through an output optical fiber 225.

There are several variations of all optical switches including: micro electro mechanical systems (MEMS), liquid crystals, bubbles, thermo-optical, and electro-optical. MEMS utilize an array of tiny mirrors that are tilted to switch beams of light from one fiber to another. Liquid crystal switches transmit light through a liquid crystal structure which polarizes the light which is switched depending upon the polarization. Bubble switches utilize bubbles that act like mirrors to switch the light signals. Thermo-optical switches utilize a structure having a thermally variable refractive index to switch the light signals. Electro-optical switches have an electrically variable refractive index.

SUMMARY AND OBJECTS OF THE INVENTION

It is an object of embodiments of the invention to provide a compact and fast acting opto-mechanical wavelength switch that allows the user to remotely switch specific wavelength or waveband signals from a muxed or demuxed signal. In an embodiment, an input signal is directed towards a switch which either aligns a normal optical fiber or a Bragg grating with the input fiber in response to a control signal. Signals having the resonant frequency of the Bragg grating are reflected while optical signals having different frequencies pass through the wavelength switch to one of the outlet optical fibers.

It is a further objective of embodiments of the invention to provide an optical wavelength switch which aligns either a normal optical fiber or a Bragg grating between both an input fiber and a single output fiber in response to a control signal. In this embodiment, all muxed signals pass through the wavelength switch to the output fiber when the normal optical fiber is inserted. When the Bragg grating is inserted, the resonant frequency signals are reflected and the signals having different frequencies pass through to the output fiber.

In one embodiment of the present invention, the optical fibers and Bragg gratings of the wavelength switch are mounted in an input block, a center block, and an output block. The input block contains the input fiber and the output block contains the output fiber. The center block mounted between the input block and the output block contains a normal optical fiber and one or more Bragg gratings mounted in parallel across the width of the center block. The center block switches between a first position (off) where the normal optical fiber is aligned between the input and output fibers and a second position (on) where the Bragg grating is aligned with the

input and output fibers. An actuator may be used to control the position of the center block. Alignment rods or pins may be used with the input, center and output blocks to simplify the alignment of optical components of the wavelength switch.

In another embodiment, the Bragg grating and a cover which is made of a low thermal coefficient material or a negative thermal coefficient material may be mounted between two ferrules to form a temperature insensitive Bragg grating assembly. The cover may be made of a material which has a low thermal coefficient of expansion and prevents the Bragg grating from expanding or contracting in response to variations temperature. Because the Bragg grating is held at a substantially constant length, the resonance frequency is stabilized over a wide range of operating temperatures.

In an embodiment of the opto-mechanical switch, an input optical fiber and an output optical fiber may be mounted in ferrules fastened to a center groove in a lower V-groove block with a gap between the ends of the input fiber and the output fiber. An upper V-groove block can travel horizontally relative to the lower V-groove block and moves the normal fiber and the Bragg grating between the center groove and adjacent grooves. In the "off" position, a normal optical fiber is inserted between the input and output fibers and all signals traveling through the input pass through to the output fiber. In the "on" position a Bragg grating is inserted between the input and output fibers so that frequency signals travelling through the input fiber are reflected back and do not pass through to the output fiber.

In yet another embodiment, a plurality of center blocks each having a different resonant frequency Bragg grating are mounted in series between the input and output blocks, allowing multiple frequencies to be switched. In alternative embodiments,

several Bragg gratings are mounted on a single center block and the input and output fibers are moved into alignment with a selected Bragg grating in response to a control signal.

In an embodiment, the inventive wavelength switch may also be combined with other optical components such as circulators or couplers to form 2 x 2 switches. In the 2 x 2 configuration, the wavelength switch includes an input fiber, an add fiber, an output fiber and a drop fiber. With the normal optical fiber inserted in the wavelength switch, all signals from the input fiber are directed to the output fiber and all signals from the add fiber are directed to the drop fiber. When the Bragg grating is inserted into the switch, resonant frequency signals are directed from the input fiber to the drop fiber and resonant frequency signals from the add fiber are directed to the output fiber. When the Bragg grating is inserted, non-resonant frequency signals from the input fiber are directed to the output fiber and non-resonant frequency signals from the add fiber are directed to the drop fiber. Again multiple Bragg gratings may be inserted in series within the wavelength switch allowing signals having various frequencies to be switched.

Other objects, features, and advantages of the present invention will be apparent from the accompanying drawings and from the detailed description that follows below.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings, in which like references indicate similar elements, and in which:

Figure 1A illustrates a point to point optical network;

Figure 1B illustrates a ring type optical network;

Figure 1C illustrates a mesh type optical network;

Figure 2 illustrates reconfigurable optical add/drop multiplexer using all optical switches;

Figures 3A and 3B illustrate a two block wavelength switch, according to one embodiment of the present invention;

Figure 3C and 3D illustrate a three block wavelength switch, in accordance with an embodiment of the present invention;

Figure 4 illustrates an embodiment of a wavelength switch with an actuator assembly;

Figure 5A and 5B illustrate a three block wavelength switch, according to one embodiment of the present invention;

Figure 6 illustrates a wavelength switch having V-groove blocks, in accordance with one embodiment of the present invention;

Figure 7A illustrates an optical element coupling device having V-groove blocks, according to one embodiment of the present invention;

Figure 7B illustrates a coupling device adapter having an optical connector in accordance with an embodiment of the present invention;

Figure 8 illustrates an optical wavelength switch having multiple Bragg gratings aligned in series, in accordance with one embodiment of the present invention;

Figure 9 illustrates a wavelength switch and an actuator in a package housing in accordance with an embodiment of the present invention;

Figure 10 illustrates an embodiment of the wavelength switch combined with circulators;

Figure 11 illustrates an embodiment of the wavelength switch in combination with an interleaver and circulators;

Figure 12 illustrates multiple wavelength switches in combination with circulators, muxing and demuxing devices according to one embodiment of the present invention;

Figure 13 illustrates an embodiment having groups of the wavelength switches in combination with circulators;

Figure 14 illustrates an embodiment of a wavelength switch having high speed X-Y stages and multiple Bragg gratings;

Figure 15 illustrates a wavelength switch using a Mach-Zehnder interferometer structure in accordance with one embodiment of the present invention, according to one embodiment of the present invention;

Figure 16 illustrates the wavelength switch having a coupler type fiber Bragg grating, in accordance with another embodiment of the present invention;

Figure 17A illustrates a view of a temperature insensitive Bragg grating assembly according to an embodiment of the present invention;

Figure 17B illustrates a side sectional view of a temperature insensitive Bragg grating assembly according to another embodiment of the present invention;

Figures 18A and 18B illustrate a lower V-groove block of a wavelength switch according to an embodiment of the present invention;

Figures 19A and 19B illustrate a sectional side view of the V-groove block wavelength switch in accordance with an embodiment of the present invention; and

Figures 20A and 20B illustrate a sectional side view of the V-groove block wavelength switch in accordance with an alternate embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

An optical wavelength opto-mechanical switch is described. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be evident, however, to one of ordinary skill in the art, that the present invention may be practiced without these specific details. The description of preferred embodiments is not intended to limit the scope of the claims appended hereto.

Opto-mechanical switches are used to route optical signals through optical networks. A single optical fiber may carry 32 or more frequencies each transmitting data at 2.5 or more gigabits per second. The inventive wavelength switch is frequency specific and is compatible with all types of digital signals.

An embodiment of the inventive opto-mechanical wavelength switch is illustrated in Figures 3A and 3B. In this embodiment, an input optical fiber 305 is mounted within an input block 303 and an end of the input fiber 305 abuts a planar surface of the input block 303. A first output fiber 317 and a Bragg grating 323 optically attached to the end of a second output fiber 315 are mounted in an output block 307. The fiber Bragg grating 323 is a short section of optical fiber in which the core refractive index has a periodic modulation or grating that reflects light over a narrow spectral range centered at a resonant wavelength known as the Bragg wavelength. An end of the first output fiber 317 and an end of the Bragg grating 323 abut a planar surface of the ouput block 307. The input block 303 and output block 307 slide against each other so that the input fiber 305 may be aligned with the Bragg grating 323 or the normal first output fiber 317. With reference to Figure 3A, the switch 302 is illustrated in a first position with the inlet optical fiber 305 aligned with

a first output optical fiber 317. In this switch position, all signals traveling through the input pass through to the first output fiber 317 without altering the signals. Figure 3B illustrates the switch 302 in the second position where a Bragg grating 323 connected to a second output optical fiber 315 is aligned with the input optical fiber 305. The signals from the input fiber 305 enter the Bragg grating 323 which reflects resonant frequency signals back through the input optical fiber 305. The non-resonant frequency signals pass through the Bragg grating 323 and through the second output optical fiber 315.

Figures 3C and 3D illustrate an embodiment of a two position opto-mechanical wavelength switch 301 which includes an input block 303, a center block 309 and an output block 315. An input optical fiber 305 is the same as that described in Figures 3A and 3B. A single output optical fiber 317 is mounted in the output block 315 and an end of the output fiber 317 abuts a planar surface of the output block 315. The center block 309 is mounted between the input block 303 and the output block 315. A normal optical fiber 321 and a fiber Bragg grating 323 are mounted in parallel across the width of the center block 309 the ends of these optical components abut planar side surfaces of the center block 309. In Figure 3C, the opto-mechanical wavelength switch 301 is illustrated in the first position with the normal optical fiber 321 aligned with the input fiber 305 and the output fiber 317 so that all signals pass through the wavelength switch 301. In Figure 3D, the opto-mechanical wavelength switch 301 is illustrated in the second position with a fiber Bragg grating 323 inserted between the input fiber 305 and the output fiber 317. As discussed, the fiber Bragg grating 323 reflects signals that match the resonant frequency of the Bragg grating 323 back through the input fiber 305.

Referring to Figure 4, the center block 309 of the opto-mechanical switch 301 is moved by an actuator 451 between a first position with the normal optical fiber 321 aligned with the input fiber 305 and the output fiber 317 and a second position with the Bragg grating aligned with the input fiber 305 and the output fiber 317. The actuator 451 may be a fast acting electro-mechanical device, such as a solenoid or any other fast acting actuator. Due to the high switching rate requirements of optical data transmission, the switching speed may be less than 10 milliseconds. In an embodiment, the actuator 451 may also have a latching mechanism which keeps the center block 309 switched in its last position even if power to the actuator 451 is cut off. This feature helps to maintain the flow of information through the switch 301 even if there is a loss of power to the actuator 451.

The required area of the switch and actuator is minimized by mounting the actuator 451 directly under the center block 309. The actuator 451 may have levers 453 connected to the center block 309 that move the center block 309 between the input block 303 and the output block 315. In alternative embodiments, the actuator 451 may engage any other portion(s) of the switch 401 so that the center block 309 is moved relative to the input block 303 and the output block 315 in response to a control signal.

In order to minimize signal losses through the wavelength switch, it is desirable to have the adjoining ends of optical fibers or other optical elements highly polished and placed as close together as possible. Reflective signal losses may be minimized by slant polishing the ends of the optical fibers to approximately 8°. In an embodiment the optical fiber and/or Bragg grating are slant polished after securing the optical elements to their appropriate blocks. The exposed end of the optical

element(s) and the planar block surface(s) may be polished simultaneously. The polished planar surface may be approximately 8° off perpendicular to the associated optical components.

Gaps between the aligned and adjoining fibers or Bragg gratings also reduce the transmitted signal strength. In the preferred embodiment of the wavelength switch, the gap between the adjoining fibers or Bragg gratings is minimized by compressing the center block between the input block and output block against. The compression of the center block may compensate for irregularities in the adjoining surfaces. For example if the surface finishes are not perfectly flat the compression may compensate for some surface irregularities such as variations in dimensional tolerances, manufacturing irregularities, and thermal expansion. With proper alignment of the optical elements, the signal losses through the inventive wavelength switch may be less than 0.1 dB. The compression can be achieved by various mechanisms including: springs, magnetic, fluid pressure, gravity, force transducers or any other suitable mechanical device.

The compression force should not be high enough to create a significant amount of friction between adjacent sliding components of the opto-mechanical switch. To further minimize friction a lubricant may be placed between sliding blocks of the switch. Appropriate lubricants include matching oils which reduce reflected signal losses through the switch. In other embodiments, precision bearings may be used to reduce friction between sliding parts. Bearings may include ball bearings, needle bearings, thrust bearings and air bearing systems.

All optical component materials have an index of refraction which indicates the angle of refraction of the light waves. In order to reduce the signal losses, a

material having the same refractive index as the optical fibers may be placed between optical components within the opto-mechanical switch. In an embodiment, an optical gel or optical liquid having a similar refractive index to that of the input fiber, output fiber and Bragg grating may flow into the small gaps between the optical components of the opto-mechanical switch to reduce signal losses.

An embodiment of the wavelength switch 501 is illustrated in Figures 5A and 5B which uses rods 531 and springs 533 to compress the input block 503 and the output block 515 against the center block 509. Two rods 531 are secured to the input block 503 and pass through slots 541 in the center block 509 and holes 545 in the output block 515. The rods 531 fit closely within the holes 545 of the output block 515 and only allow the output block 515 to move along the axis of the rods 531. The engagement of the rods 531 and slots 541 allow the center block 509 to slide between the input block 503 and the output block 515. The springs 533 are compressed between the outer end of the output block 515 and the ends of the rods 531. The compressed springs 533 put the rods 531 in tension which squeezes the center block 509 between the input block 503 and the output block 515.

The rods 531 and slots 541 may also assist in aligning the normal optical fiber 521 and the fiber Bragg grating 523 with the input fiber 505 and the output fiber 517. As discussed, the rods 531 slide within the width of the slots 541 allowing the center block 509 to slide between the input block 503 and the output block 515. The ends of the slots 531 provide two alignment stops for the center block 509. With reference to Figure 5A, when the center block 509 is at a first stop position, the normal optical fiber 521 is aligned with the input fiber 505 and output fiber 517. With reference to Figure 5B, when the center block 509 is at the second stop position, the fiber Bragg

grating 523 is aligned with the input fiber 505 and the output fiber 517. In other embodiments, other mechanisms may be used to provide alignment stops for the center block 509 so that either the normal optical fiber or the Bragg grating is aligned with the input and the output fibers. The alignment stops may be any suitable mechanism including: posts mounted outside the exposed ends of the center block, pins that slide within grooves.

In another embodiment, the input, center, and output block may be fabricated using a molding process. The optical fibers, Bragg grating and the rods may be molded into the blocks and inherently secured within the blocks. Alternatively, the holes and slots in the blocks may also be molded or machined into the blocks and the rods, optical fibers, and Bragg grating may be inserted into holes and slots. An adhesive or any other suitable fastening process, material or device may be used to secure the rods and optical elements within the holes in the blocks.

Referring to Figure 6, an embodiment of the wavelength switch 601 is illustrated with V-groove blocks used for the input block 603, the center block 609 and the output block 615. The V-groove blocks have uniformly spaced V-grooves across at least one surface and may be metal, plastic, ceramic or any other suitable material. The optical fibers, Bragg gratings and rods are placed in the grooves and secured in place with covers 663. Slots 641 may be formed on either side of the normal fiber 621 and a Bragg grating 623 in the center block 609 by removing material between adjacent grooves and placing a cover 663 on the center block. The rods 631 pass through slots 641 in the center block 609 which allows the center block 609 to slide between the input block 603 and output block 615. The covers 663 may be secured to the V-groove with screws, adhesives or any other suitable fastening

device. Again, the ends of the groove may function as stops for positioning the center block between "on" and "off" positions with the Bragg grating and normal fiber aligned between the input and output fibers.

With reference to Figure 6, the grooves in the blocks are evenly spaced apart, thus the slots 641 that are two grooves wide may provide stops for the rods 631. As discussed, ends of slots 641 in the center block 609 may be used as alignment stops for the wavelength switch 601. When the center block 609 is moved in one direction, the rods 631 but up against one end of the slots 641 and the normal optical fiber 621 is aligned with the input fiber 605 and the output fiber 617. When the center block 609 is moved in the opposite direction, the rods 631 butt up against the second end of the slots 641 which aligns the fiber Bragg grating 623 with the input fiber 605 and the output fiber 617.

In an embodiment, the V-groove blocks may have adjacent grooves that are separated by approximately 250 μm and which are configured to securely hold 125 μm diameter optical fibers and fiber Bragg gratings. The insulative layer of the optical fibers may be removed prior to securing the optical fiber or Bragg grating in the V-groove. The V-grooves may be enlarged to accommodate optical elements, Bragg gratings, and alignment rods of various sizes. For example, alignment pins having diameters between 125 μm and 1 mm may be secured to the V-grooves of the switch blocks. As discussed, slots may be formed in the center block by removing material between adjacent grooves or by fabricating any of the blocks with slots. The slots may have a width slightly larger than the diameter of the alignment rods so that the rods can freely slide along the length of the slots.

Referring to Figure 7A, it is also possible to use the V-groove block embodiment of the inlet block and outlet block as an optical fiber connector. The input fiber 605 may be connected to the output fiber 617 by connecting the input block 603 to the output block 615. The input block 603 and the output block 615 may be held together by placing rods 631 in the grooves on either side of the input fiber 605 and output fiber 617. With the input block 603 and output block 615 properly aligned with each other, the rods 631 can be secured to the input block 603 and the output block 615 with clamping covers or any other suitable attachment mechanism.

The V-groove block connectors may be used as a universal connector for joining optical devices or fibers to one another. For example, the V-groove block connectors can be used to connect muxers, circulators, switches or any other device having V-groove blocks at the input and output optical fibers. The V-groove block connectors create a modular system that allows any optical components to be easily interconnected. Existing optical components use regular optical connectors. However, with reference to Figure 7B, an adapter 771 is illustrated which may be used to connect the optical connector 773 to V-groove block connector 701 which can be connected to a mating V-groove block connector 703. In other embodiments, multiple optical fibers may be placed in multiple adjacent grooves of the V-groove block to form a multiple optical fiber connector.

In Figure 8, another embodiment of the wavelength switch 801 having multiple Bragg gratings is illustrated. The wavelength switch 801 includes multiple center blocks 809 configured in series to selectively reflect selected frequencies. The center blocks 809 may be configured between the input block 803 and the output block 815. Each center block 809 may have a different resonant frequency Bragg

grating 823 and a normal optical fiber 821 which are mounted in parallel across the width of the center blocks 809. The Bragg grating 823 or the normal optical fiber 821 of each center block 809 are selectively aligned in series with the input fiber 805 and the output fiber 817. A muxed input signal containing many different frequency signals may be transmitted through the wavelength switch 801. The signal frequencies that encounter corresponding Bragg gratings 823 are reflected back while the remaining frequencies pass through to the output fiber 817. The position of each center block may be controlled by an actuator that responds to a control signal. By switching on various resonant wavelength Bragg gratings selected frequencies can be filtered out of the original muxed signal.

With reference to Figure 9, the actuator 451 and the wavelength switch 301 may be mounted in a package 961 which resembles a hollow block. The package 961 provides a support frame for the actuator 451 and the wavelength switch 301 and may be configured to be easily connected to other packages. The actuator 451 and/or the wavelength switch 301 can be independently removed from the package 961 for repair, replacement or modification without having to disassemble other components of the switch assembly or other packages in the modular system. The packages 961 are easily mounted on a board and allow any other optical devices mounted in packages 961 to be easily interconnected as modules of an optical system. The package system may be used with any of the disclosed wavelength switch and connector embodiments.

The inventive wavelength switches may be combined with many different optical components to form 2 x 2 switches that are similar to item 217 described with reference to Figure 2 in the Background section. In an embodiment, the inventive

wavelength switches may be combined with circulators to produce 2 x 2 switches. Circulators are well known in the optical art and can direct the path of light signals depending upon the signal's direction of travel through the circulator. With reference to Figure 10, light signals traveling through input fiber 1005 towards the 2 x 2 switch 1001 enter the circulator 1083 and exit through optical fiber 1077. Signals that are traveling in a reverse direction through optical fiber 1077 enter the circulator 1083 and are diverted to a "drop" optical fiber 1081. Signals traveling from the drop optical fiber 1081 towards the input circulator 1083 will be diverted to back through the input fiber 1005. By combining the Bragg grating switches with the circulators, individual signals can be added or dropped between the input fiber and the output fiber.

In the embodiment illustrated in Figure 10, the 2 x 2 wavelength switch 1001 incorporates the wavelength switch described earlier with reference to Figure 8. In this embodiment, the 2 x 2 wavelength switch 1001 has four Bragg grating center blocks 1009 that are configured in series between an input circulator 1083 and an output circulator 1087. An input fiber 1005 and a drop fiber 1081 are connected to the input circulator 1083 and an output fiber 1017 and an add fiber 1089 are connected to the output circulator 1087. In this example, the center blocks 1009 having resonant wavelengths λ1, λ2, λ3, and λ4. The Bragg gratings 1023 λ1 and λ3 are aligned with the input fiber 1005 and the output fiber 1017. A muxed input signal containing λ1, λ2, λ3, and λ4 signals is transmitted through the input fiber 1005 and passes through the input circulator 1083. The λ1 and λ3 signals are reflected at the λ1 and λ3 center blocks 1009 back towards the input circulator 1083. At the input circulator 1083, the λ1 and λ3 signals are redirected to the drop fiber 1081. The λ2

and λ4 signals pass through the center blocks and the output circulator 1087 to the output fiber. By varying the aligned Bragg gratings 1023, any combination of signal frequencies can be switched from the output fiber 1017 to the drop fiber 1081. In other embodiments, the opto-mechanical switch may have any number of center blocks each containing a different resonant wavelength Bragg gratings.

Additional signals having the resonant wavelengths λ1 and λ3 may be added to the output fiber 1017 through the add fiber 1089. The λ1 and λ3 add signals enter the output circulator 1087 and are directed towards the center blocks 1009. The λ1 and λ3 add signals are reflected back towards output circulator 1087 at the λ1 and λ3 Bragg gratings 1023 respectively. The λ1 and λ3 add signals pass through the output circulator 1087 to the output fiber 1017. The frequencies that do not match the resonant frequencies of the Bragg gratings aligned within the switch will pass through the drop fiber 1081. Additional wavelength signals may be controlled by adding additional Bragg grating filters between the input block and output block.

In other optical device embodiments the wavelength switches and circulators may be combined with interleavers. The signal frequencies muxed in an optical fiber are generally separated by a minimum frequency differential. Interleavers allow more frequencies to be transmitted through a single optical fiber by overlapping two muxed signal beams. The interference of the two beams creates a periodic, repeating output as different integral multiples of wavelengths pass through the device. The desired channel spacing is controlled by the fringe pattern of the beams. Interleavers may utilize two separate demux devices to cover the entire operating frequency range of an optical system by interleaving the channels. A first demux device separates the odd channels while a second demux device separates the even channels.

Referring to Figure 11, in an embodiment wavelength switches and circulators are combined with an interleaver 1173. An input signal which includes individual signals λ1, λ2, λ3, λ4 ... - λN and pass through an interleaver 1173 which separates the odd and even signals. The odd muxed signals λ1, λ3, λ5 ...λN pass through the first circulator 1183 and through the wavelength switches, 1191, 1195, 1199. In this example, signals λ1, λ3 and λ5 are reflected at their corresponding resonant wavelength Bragg gratings 1191, 1195, 1199 and the remaining odd λ signals pass through to a first output fiber 1117. Signals λ1, λ3 and λ5 travel back to the first circulator 1183 where they are diverted towards a second output fiber 1189. The even signals λ2, λ4, λ6 ... λN + 1 pass from the interleaver 1173 to the second circulator 1185 and the optical switches 1193, 1197. In this example, λ2 and λ4 Brag gratings 1193, 1197 are aligned with the optical fibers and signals λ2 and λ4 are reflected back to circulator 1185 and diverted to output fiber 1119. Signals λ6 - λ10 pass through to outlet leg 1121.

In an embodiment, the 2 x 2 switches having the inventive wavelength switches and circulators may be combined with muxing and demuxing devices is illustrated in Figure 12. An input signal traveling through an input fiber 1205 has a plurality of muxed signals and passes through the first circulator 1283. Signals λ1, λ2, λ3 and λN are reflected by their corresponding Bragg gratings in the wavelength switches 1291, 1293, 1295, 1297. The reflected signals λ1, λ2, λ3 and λN are diverted by the first circulator 1283 to the demux device 1275 which separates the muxed signals into individual signals. The unswitched signals λ5, λ6, ...λN pass through the wavelength switches 1291, 1293, 1295, 1297 and the second circulator

1287 to the output fiber 1217. Individual add signals λ1, λ2, λ3 and λN are input into the mux device 1277 and pass through an add fiber 1289 to the second circulator 1287 where they are directed towards the wavelength switches 1291, 1293,1295, 1297. The λ1, λ2, λ3 and λN add signals are reflected by the wavelength switches 1291, 1293, 1295, 1297 back through the second circulator 1287 and are added to the muxed output signals traveling through the output optical fiber 1217.

In yet another embodiment, circulators and wavelength switches may be arranged in a cascading configuration as illustrated in Figure 13. In this example, λ1, λ2, λ3 and λ4 signals are transmitted through inlet fiber 1305 and pass through a first circulator 1381 to a first set of wavelength switches 1391. The first set of wavelength switches 1391 reflect any corresponding Bragg grating frequencies that are aligned or switched "on". The reflected signals are diverted by the first circulator 1381 to a first output leg 1321. The unreflected signals pass through the second circulator 1383 and pass through a second set of wavelength switches 1393. The selected frequencies are again reflected back to the second circulator 1383 and diverted to a second output fiber 1323. The process continues with other signals being diverted to output legs 1325 and 1327. Any remaining signals pass through to the output fiber 1317. In this embodiment, individual or muxed signals can be diverted to any of the output fibers 1317, 1321, 1323, 1325, 1327. In other embodiments, this cascading configuration can be expanded with more Bragg grating switches and more circulators.

In another embodiment illustrated in Figure 14, the wavelength switch includes several fiber Bragg grating mounted in parallel on a single center block 1409. The input block 1403 and output block 1415 are mounted on high speed X-Y stages 1421, 1425 which move in parallel along either side of the center block 1409. The

flexible nature of the input fiber 1405 and output fiber 1417 allow the inlet block 1403 and outlet block 1415 to move on the X-Y stages 1421, 1425 to engage any one of the Bragg gratings in the center block 1409 without effecting the signals traveling through the fibers. The X-Y stages 1421, 1425 move the input fiber 1405 and the output fiber 1417 into alignment at opposite ends of the specified Bragg grating 1423 in response to a control signal. Once the Bragg grating 1423 is aligned with the input fiber 1405 and the output fiber 1417, the wavelength switch 1401 operates like a 2 x 2 switch described in prior embodiments.

In an embodiment of the wavelength switch illustrated in Figure 14, the input block 1403 and output block 1415 have protruding pins (not shown) that engage slots (not shown) in the center block 1409 to assist in aligning the input fiber 1405 and the output fiber 1417 with the selected Bragg grating. The Bragg gratings may be arranged in parallel on the center block 1409 in groups of two that are separated by at least one slot formed on either side of the Bragg gratings. In operation, the input block 1403 and output block 1415 are positioned by two X-Y stages 1421, 1425 that move in parallel along the length of the center block 1409 to the appropriate set of Bragg gratings. The input block 1403 and output block 1415 are then moved against the center block 1409 and the alignment pins engage the slots on either side of two Bragg gratings. The alignment pins are then moved against the stop ends of the slots so that the inlet fiber 1405 and the outlet fiber 1417 are aligned with the selected Bragg grating. The input block 1403 and the output block 1415 may be held in this position until a new Bragg grating is selected. The slots may have a length that allows the alignment pins having a diameter of about 125 μm to 1 mm to travel precisely 250 μm.

In another embodiment illustrated in Figure 15, the wavelength switch 1501 has a Mach-Zehnder interferometer structure. In this embodiment, the center block 1509 contains two Bragg gratings 1523 and two sections of normal optical fiber 1521 and moves between an input coupler 1573 and an output coupler 1577. A muxed input signal is transmitted through the input fiber 1505 of the input coupler 1573 where it is split into two optical fibers that intersect the center block 1509. If the center block 1509 is switched "off", the muxed signals travel through the normal fibers 1521 in the center block 1509 to the output coupler 1577 and out through the output fiber 1517. If the center block 1509 is switched "on", the muxed input signals travel through the Bragg gratings 1523 in the center block 1509 and the resonant frequency signals are reflected back through the input coupler 1573 and out through the drop fiber 1581. The remaining muxed signals travel through the output coupler 1577 and out through the output fiber 1517. Signals having the resonant frequency of the Bragg gratings 1523 may be transmitted through the add fiber 1589, reflected at the Bragg gratings 1523, and combined with the muxed signals traveling through the output fiber 1517.

Figure 16 illustrates yet another embodiment of a 2 x 2 wavelength switch 1601 that includes a coupler type fiber Bragg grating 1623. In an "off" position, a normal optical fiber 1621 is aligned between the input fiber 1605 and the output fiber 1617, such that a signal passes directly through the center block 1609. In the "off" position, the add and drop legs are misaligned with all optical components of the center block 1609. In the "on" position, the input fiber 1605 and the drop fiber 1681 are connected to two legs on one side of the coupler type fiber Bragg grating 1623 and the add fiber 1689 and the output fiber 1617 are connected to two legs on an opposite

side of the coupler type fiber Bragg grating 1623. The muxed signals are transmitted through the input fiber 1605 and muxed signals that have the Bragg grating 1623 resonant frequency are reflected back through the drop fiber 1681. The remaining muxed signals travel through the Bragg grating 1623 and through the output fiber 1617. The resonant frequency add signals are transmitted through the add fiber 1689, reflected by the Bragg grating 1623 and combined with the muxed signals transmitted through the output fiber 1617.

When the temperature of the Bragg grating changes, the center (resonant) wavelength may also change proportionally. The Bragg grating resonant frequency changes by as much as 0.01 nm per degree centigrade increase in temperature resulting in a proportional rise in the resonant wavelength. Conversely, a drop in temperature will cause the resonant wavelength to decrease.

If the wavelength switch is in a thermally dynamic environment a thermostatic device may be required to keep the Bragg grating within a specific operating temperature range. By maintaining the Bragg grating at a constant temperature the resonant wavelength remains within the required tolerances and the specific wavelength signals are reflected. In an embodiment, a Pertie thermo module or any other suitable thermostatic device may be mounted on or in the center block to keep the Bragg grating at a constant temperature.

Since the rise in the temperature of the grating results in the increase of the Bragg resonance wavelength it is necessary to reduce the grating periodicity to compensate the temperature effect and make the Bragg grating temperature-independent. This is accomplished by pre-stressing the fiber grating, e.g., by tension, and then causing the tension in the grating to become essentially proportionally

relaxed as the ambient temperature is increased (or causing the tension to be stronger as the temperature is lowered). For this purpose, the temperature compensating package needs to include a structure or a structural component the length of which contracts upon heating, i.e., with a net negative coefficient of thermal expansion.

With reference to Figure 17A, a side sectional view of a temperature insensitive Bragg grating assembly 1701 is illustrated which maintains a specific resonant frequency over a wide range of operating temperatures. The temperature insensitive Bragg grating assembly 1701 includes a Bragg grating 1727 which is embedded between optical fiber 1729 which passes through concentric holes within the ferrules 1795 and are exposed at the ends of the Bragg grating assembly 1701. The Bragg grating 1727 is attached to ends of metal protrusions 1781 that extend from ceramic ferrules 1795. A cover 1797 is mounted between the ferrules 1795. Because the cover 1797 is made of a material having a low coefficient of thermal expansion the distance between the ferrules 1797 remains substantially constant regardless of the temperature.

The center wavelength of the Bragg grating 1727 made of glass can be shifted 0.01 nm in response to each gram of tension force. The Bragg grating assembly 1701 may be configured to pre-stress the Bragg grating 1727 in tension. As the temperature increases, the resonance wavelength increases. In order to compensate for the increasing resonance wavelength of the Bragg grating 1727, the metal protrusions 1781 also expand as the temperature increases which allows the Bragg grating 1727 to contract. The contraction of the Bragg grating 1727 as the temperature increases counteracts the increased resonance wavelength caused by the temperature rise. These counteracting forces allows the resonance wavelength of the

Bragg grating 1727 to remain substantially constant. Conversely, as the temperature decreases the metal protrusions 1781 contract stretching the Bragg grating 1727. The stretching of the Bragg grating 1727 as the temperature decreases counteracts the shortening resonance wavelength caused by the temperature descrease.

The temperature insensitive Bragg grating assembly 1701 may be configured in a cylindrical form as illustrated in Figure 17B. The cylindrical temperature insensitive Bragg grating assembly 1701 may have cylindrical ferrules 1795 and a tubular cover 1797 that is mounted around the Bragg grating 1727. The tubular structure of the temperature insensitive Bragg grating assembly 1701 allows it to be mounted in V-groove blocks as well as all other embodiments of the inventive opto-mechanical switch.

In Figures 18A and 18B, another embodiment of the opto-mechanical wavelength switch 1801 is illustrated. The opto-mechanical switch 1801 includes a lower V-groove block 1809, an input fiber assembly 1805, a Bragg grating assembly 1827, a normal optical fiber 1821 and an output fiber 1817. Cylindrical ferrules 1893 are mounted on the ends of the optical elements of the opto-mechanical switch 1801. The input fiber 1805 and the output fiber 1817 are mounted in ferrules 1893 that are fastened to a center groove of the lower V-groove block 1809 and separated by a specific distance. Optical elements that are placed in a common V-groove are precisely aligned because the ferrules 1893 have the same diameter and the optical elements are concentrically mounted. In an embodiment the lower V-groove block 1809 may be ceramic, plastic, metal or any other suitable material. The ferrules 1893 have a circular cross section and may be made of metal, ceramic, plastic or other

durable material that can protect the optical elements from damage during rolling or sliding between grooves in the lower V-groove block 1809.

In the "off" position illustrated in Figure 18A, the normal fiber 1821 is inserted between the input fiber 1805 and the output fiber 1817, and the Bragg grating 1827 is placed in an adjacent groove. The length of the normal fiber 1821 closely matches the distance between the input fiber 1805 and the output fiber 1817 so that the ferrules 1893 are very closely spaced and the signal losses through the opto-mechanical switch 1801 are very low. In the "on" position as illustrated in Figure 18B, the Bragg grating 1827 is inserted between the input fiber 1805 and the output fiber 1817 and the normal fiber 1821 is placed in an adjacent groove. Again because the length of the Bragg grating 1827 closely matches the space between the input fiber 1805 and the output fiber 1817, the ferrules 1893 are closely aligned and the signal losses are very low. In an embodiment, the temperature insensitive Bragg grating assembly illustrated in Figure 17 may be used in the opto-mechanical switch 1801. An actuator (not shown) may be used to insert either the normal fiber 1821 or the Bragg grating 1827 between the input fiber 1805 and the output fiber 1817 in response to a control signal.

Figures 19A and 19B illustrate a cross section view of an embodiment of the opto-mechanical switch 1901. An upper V-groove block 1987 having two grooves is used to slide the Bragg grating assembly 1927 and normal optical fiber assembly 1921 between grooves in the lower V-groove block 1909. In this embodiment, the Bragg grating assembly 1927 and normal optical fiber assembly 1921 may roll between the adjacent grooves of the lower V-groove block 1909 and slide against the surfaces of the grooves of the upper V-groove block 1987. The contact points between the metal

ferrules 1993 and the lower surfaces of the upper V-groove block 1987 may have a low coefficient of friction so that the sliding friction is minimal. Figure 19A illustrates the opto-mechanical switch 1901 in the "off" position with the normal fiber assembly 1921 placed in the center groove between the input and output fibers. Figure 19B illustrates the switch 1901 in the "on" position with the Bragg grating assembly 1927 placed in the center groove. An actuator (not shown) may be attached to the upper V-groove block 1987 so that the opto-mechanical switch 1901 can be remotely controlled. The actuator will align either the normal fiber 1921 or the Bragg grating assembly 1927 between the input and output fibers in response to a control signal. Again the Bragg grating assembly 1927 may be the temperature insensitive Bragg grating assembly disclosed with reference to Figure 17.

Figures 20A and 20B illustrate a cross section view of another embodiment of the opto-mechanical switch 2001. In this embodiment, an upper V-groove block 2087 having three grooves is used to roll the Bragg grating assembly 2027 and normal optical fiber assembly 2021 between grooves in the lower V-groove block 2009. The Bragg grating assembly 2027 and the normal optical fiber assembly 2021 may be compressed between the upper V-groove block 2087 and the lower V-groove block 2009 and the coefficient of friction between the ferrules 2093, the lower V-groove block 2009 and the upper V-groove block 2087 is high to prevent the ferrules 2093 from sliding. The upper V-groove block 2087 securely holds the Bragg grating assembly 2027 and normal optical fiber assembly 2021 within the grooves of the lower V-groove block 2009 to accurately alignment between the input fiber and the output fiber. Again, an actuator (not shown) may be attached to the upper V-groove block 2087 to align either the normal fiber assembly 2021 or the Bragg grating

assembly 2027 between the input and output fibers in response to a control signal. The Bragg grating assembly 2027 used in this embodiment may be a temperature insensitive Bragg grating assembly.

In the foregoing, an opto-mechanical switch for fiber optic communications networks is described. In all of the disclosed embodiments, the wavelength switches may be toggled by actuators in response to a control signal. The wavelength switch assemblies may include rods which engage slots to provide alignment stops for the optical fibers and Bragg gratings. Although the present invention has been described with reference to specific exemplary embodiments, it will be evident that various modifications and changes may be made to these embodiments without departing from the broader spirit and scope of the invention as set forth in the claims. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense.

CLAIMS

What is claimed is:

1. An opto-mechanical switch, comprising:

an input block having an input optical fiber that abuts a surface of the input block;

an output block having an output optical fiber that abuts a surface of the output block;

a center block having an insert optical fiber and a fiber Bragg grating, wherein a first end of the insert optical fiber abuts a first surface of the center block and a second end of the insert optical fiber abuts a second surface of the center block and a first end of the fiber Bragg grading abuts a first surface of the center block and a second end of the fiber Bragg grading abuts a second surface of the center block;

wherein the center block is positioned between the input block and the output block and the center block is movable relative to the input block and the output block between a first position which aligns the input optical fiber with the first end of the insert optical fiber and the output optical fiber with the second end of the insert optical fiber and a second position which aligns the input fiber with the first end of the fiber Bragg grating and the output fiber with the second end of the fiber Bragg grating.

2. The opto-mechanical switch of claim 1 further comprising: an actuator which moves the center block between the first position and the second position in response to an electrical signal.

3. The opto-mechanical switch of claim 2 further comprising: a latch that keeps the center block in the first or the second position when power to the actuator is terminated.

4. The opto-mechanical switch of claim 1 wherein the surface of the inlet block, the surface of the outlet block, the first surface of the center block and the second surface of the center block are all planar.

5. The opto-mechanical switch of claim 1 further comprising: an input circulator having an inlet fiber, and outlet fiber and a drop fiber; wherein the outlet fiber of the input circulator is in communication with the input optical fiber in the input block.

6. The opto-mechanical switch of claim 1 wherein the fiber Bragg grating is fastened to a cover made of a material that has a low or a negative coefficient of thermal conductivity.

7. The opto-mechanical switch of claim 1 further comprising:

a thermostatic module that can keep the fiber Bragg grating within a specific temperature range.

8. The opto-mechanical switch of claim 1 further comprising:

a spring which compresses the input block and the output block against the center block.

9. The opto-mechanical switch of claim 1 further comprising:

a first rod that intersects the input block and the output block and wherein the first rod passes through a first slot in the center block; and

a second rod that intersects the input block and the output block and wherein the second rod passes through a second slot in the center block.

10. An opto-mechanical switch, comprising:

an input block having an input optical fiber that abuts a surface of the input block;

an output block having an output optical fiber that abuts a surface of the output block;

a first center block having a first insert optical fiber and a first fiber Bragg grating, wherein the first insert optical fiber abuts a first surface and a second surface of the first center block and the first fiber Bragg grading abuts the first surface and the second surface of the first center block;

a second center block having a second insert optical fiber and a second fiber Bragg grating, wherein the second insert optical fiber abuts a first surface

and a second surface of the second center block and the second fiber Bragg grading abuts the first surface and the second surface of the second center block;

wherein the first center block and the second center block are positioned between the input block and the output block and the first center block is movable relative to the input block between a first position which aligns the input optical fiber with the first insert optical fiber and a second position which aligns the input fiber with the fiber Bragg grating and the second center block is movable relative to the output block between a third position which aligns the output optical fiber with the second insert optical fiber and a fourth position which aligns the output optical fiber with the second Bragg grating.

11. The opto-mechanical switch of claim 10 further comprising:

a first actuator which moves the first center block between the first position and the second position in response to a first control signal; and

a second actuator which moves the second center block between the third position and the fourth position in response to a second control signal.

12. The opto-mechanical switch of claim 11 further comprising:

a first latch that keeps the first center block in the first or the second position when power to the first actuator is removed; and

a second latch that keeps the second center block in the third or the fourth position when power to the second actuator is removed.

13. The opto-mechanical switch of claim 10 wherein the surface of the inlet block, the surface of the outlet block, the first surface of the center block and the second surface of the center block are all planar.

14. The opto-mechanical switch of claim 10 further comprising:

an inlet circulator having an inlet fiber, and outlet fiber and a drop fiber;

wherein the outlet fiber of the circulator is in communication with the input optical fiber in the input block.

15. The opto-mechanical switch of claim 10 wherein the first fiber Bragg grating is fastened to a cover made of a material that has a low or a negative coefficient of thermal conductivity.

16. The opto-mechanical switch of claim 10 further comprising:

a thermostatic module that can keep the fiber Bragg grating within a specific temperature range.

17. The opto-mechanical switch of claim 10 further comprising:

a first rod that intersects the input block and the output block and wherein the first rod passes through a first slot in the first center block and a third slot in the second center block; and

a second rod that intersects the input block and the output block and wherein the second rod passes through a second slot in the first center block and a fourth slot in the second center block.

18. An opto-mechanical switch comprising:

an input block mounted on a first X-Y stage having an input optical fiber that abuts a surface of the input block;

an output block mounted on a second X-Y stage having an output optical fiber that abuts a surface of the output block;

a center block positioned between the input block and the output block having a plurality of fiber Bragg gratings, wherein first ends of the plurality of fiber Bragg gratings abut a first surface of the center block and second ends of the fiber Bragg gratings abut a second surface of the center block;

wherein the first X-Y stage and the second X-Y stage are movable relative to the center block between a plurality of positions, in each of the plurality of positions the input optical fiber and the output fiber are aligned with one of the plurality of fiber Bragg gratings in response to a control signal.

19. The opto-mechanical switch of claim 18 wherein the input block further comprises alignment rods and the output block and the center block further comprises alignment slots, wherein alignment rods engage ends of the alignment slots to align each of the fiber Bragg gratings with the input fiber and the output fiber.

20. The opto-mechanical switch of claim 18 further comprising:

an inlet circulator having an inlet fiber, and outlet fiber and a drop fiber;

wherein the outlet fiber of the circulator is in communication with the input optical fiber in the input block.

21. The opto-mechanical switch of claim 18 wherein at least one of the plurality of fiber Bragg gratings is fastened to a cover made of a material that has a low or a negative coefficient of thermal conductivity.

22. The opto-mechanical switch of claim 18 further comprising:

a thermostatic module that keeps the fiber Bragg grating within a specific temperature range.

23. The opto-mechanical switch of claim 18 further comprising:

a spring which compresses the input block against the center block.

24. An opto-mechanical switch, comprising:

an input optical fiber;

an output optical fiber;

a center optical fiber;

a fiber Bragg grating; and

a bottom block having at least three adjacent grooves;

wherein the input fiber and the output fiber are mounted in a center groove of the block and separated by a specific distance; and wherein in a first position the center optical fiber is placed in the center groove such that a first end of the center optical fiber abuts an end of the input optical fiber and a second end of the center optical fiber abuts an end of the output optical fiber and the fiber Bragg grating is placed in a first adjacent groove; and in a second position the fiber Bragg grating is placed in the center groove such that a first end of the fiber Bragg grating abuts the end of the input optical fiber and a second end of the fiber Bragg grading abuts the end of the output optical fiber and the center optical fiber is placed in a second adjacent groove.

25. The opto-mechanical switch of claim 24 wherein ferrules are mounted on the ends of the center optical fiber, the ends of the Bragg grating, the end of the input optical fiber and the end of the output optical fiber.

26. The opto-mechanical switch of claim 24 further comprising:

an actuator;

wherein the actuator moves the upper block so that either the center optical fiber or the Bragg grating are placed in the center groove in response to a control signal.

27. The opto-mechanical switch of claim 24 further comprising:

an upper block having at least two grooves

wherein the upper block is in contact with the center optical fiber and the Bragg grating and the actuator moves the upper block so that either the center optical fiber or the Bragg grating is placed in the center groove and aligned with the input fiber and the output fiber in response to a control signal.

28. The opto-mechanical switch of claim 24 wherein the fiber Bragg gratings is fastened to a cover made of a material that has a low coefficient of thermal conductivity.

29. The opto-mechanical switch of claim 24 further comprising:

a thermostatic module that keeps the fiber Bragg grating within a specific temperature range.

FIG.1A (PRIOR ART)

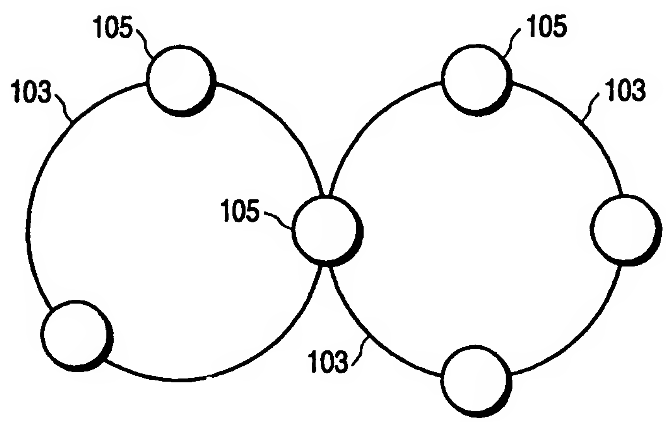


FIG.1B (PRIOR ART)

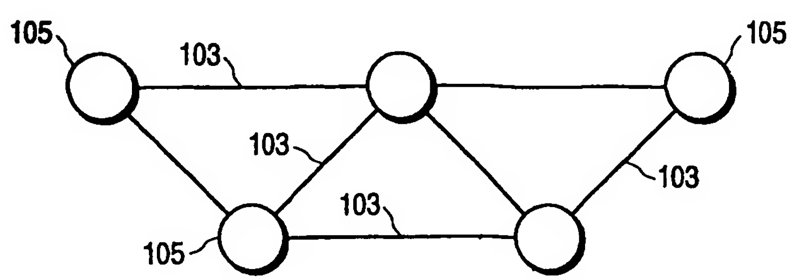


FIG.1C (PRIOR ART)

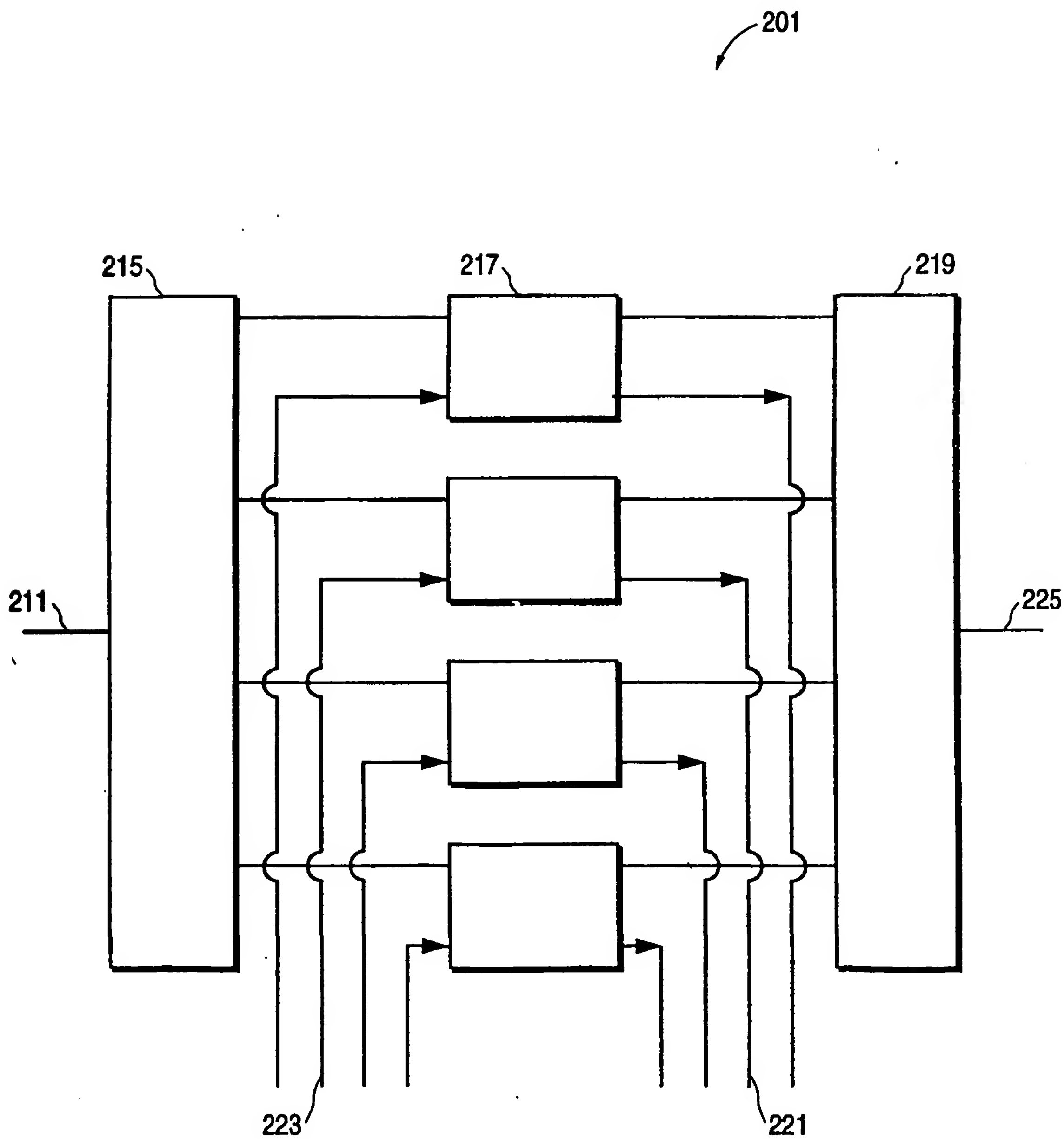


FIG.2 (PRIOR ART)

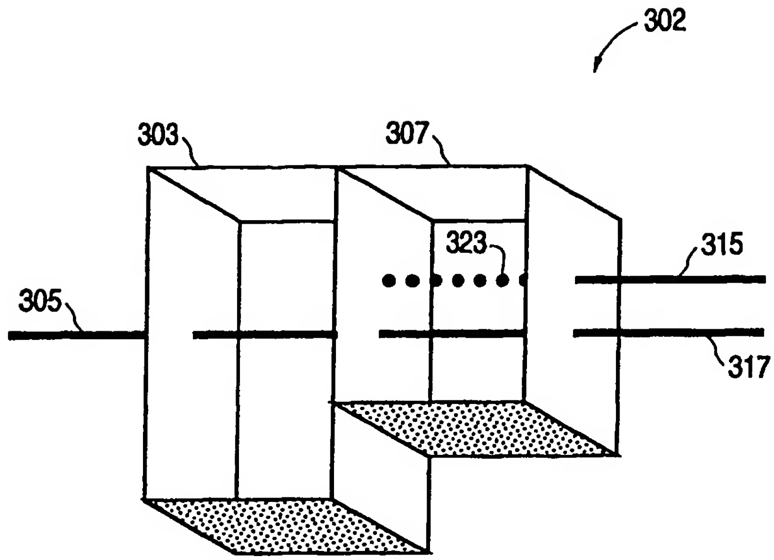


FIG.3A

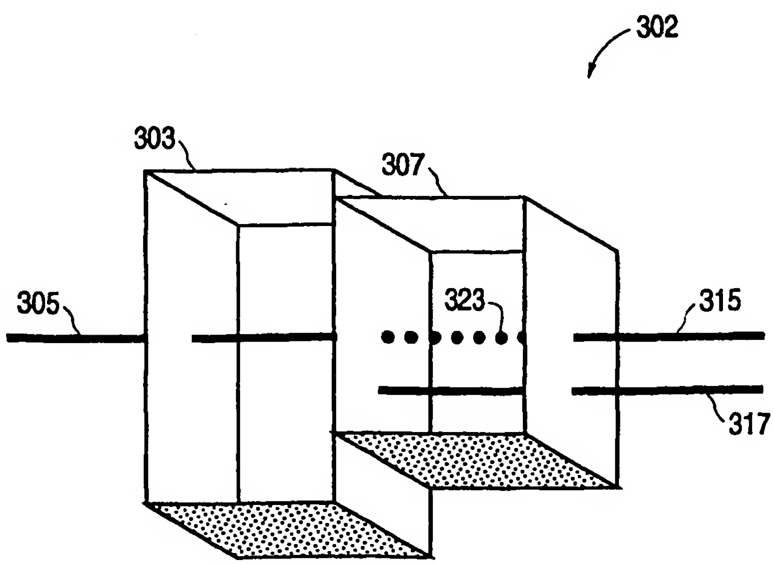


FIG.3B

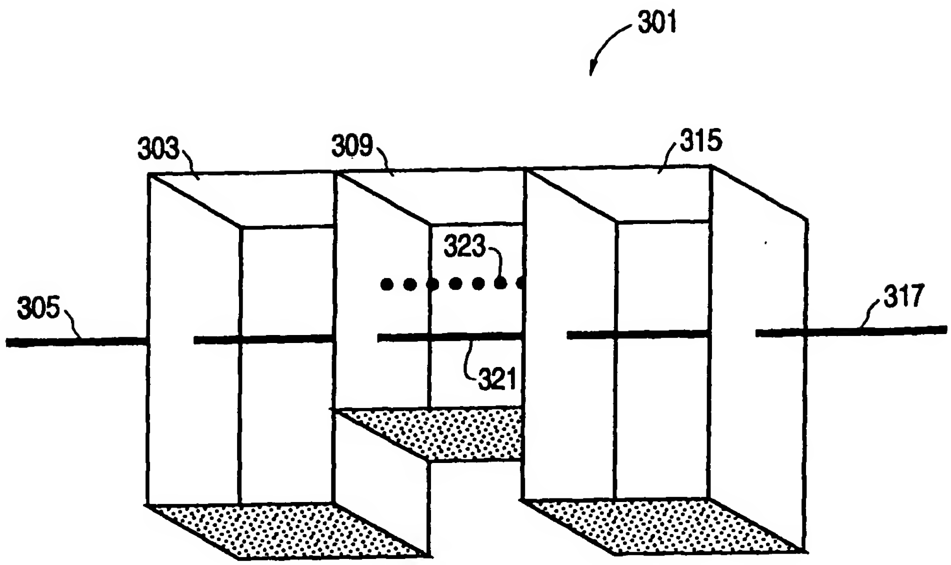


FIG.3C

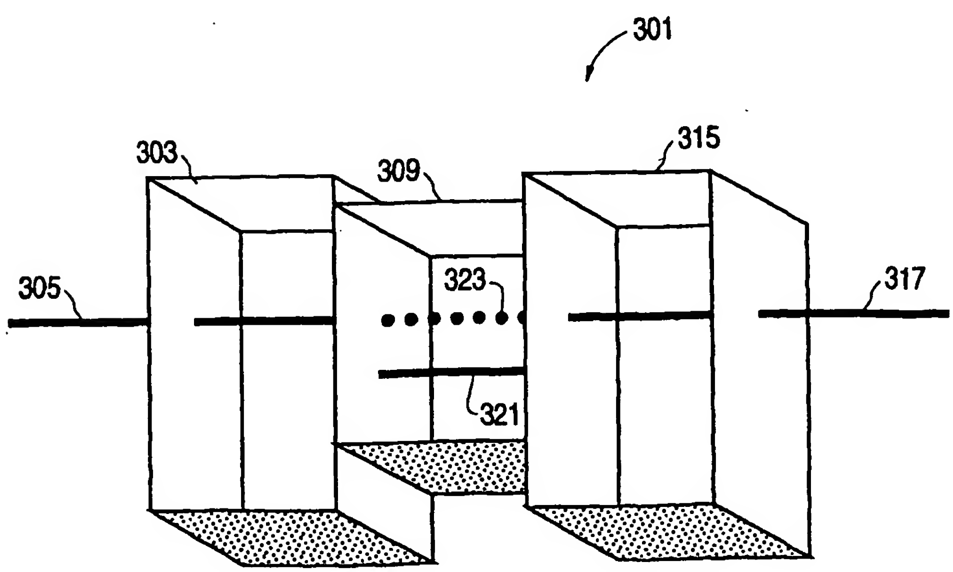


FIG.3D

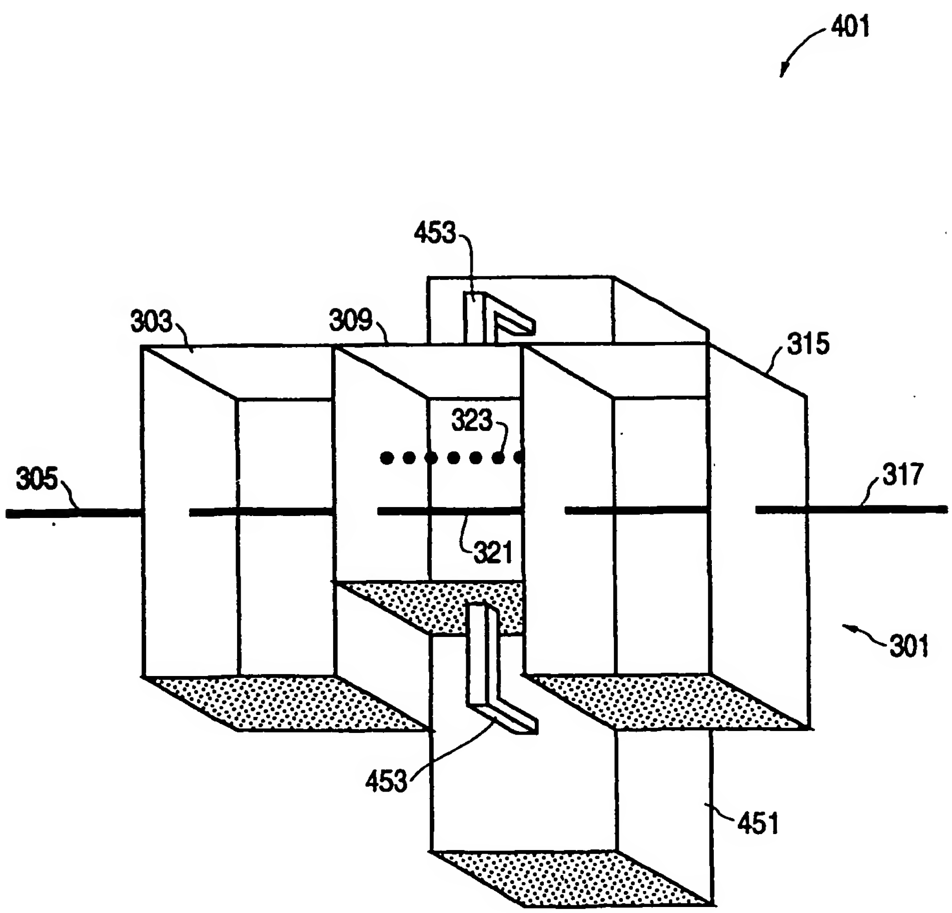
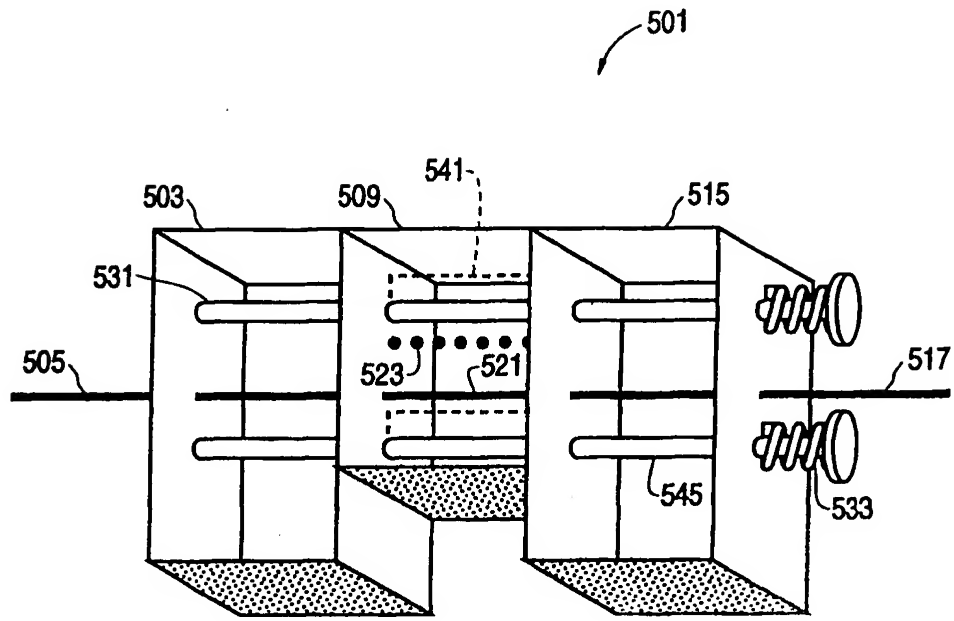


FIG.4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541
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515
531
505
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545
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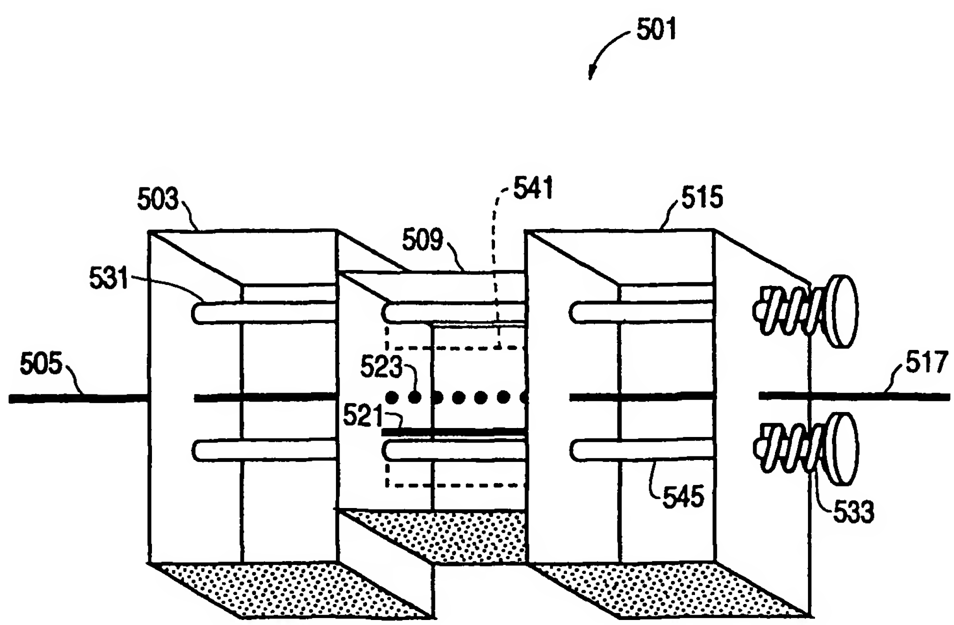
FIG.5A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517
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545
533

FIG.5B

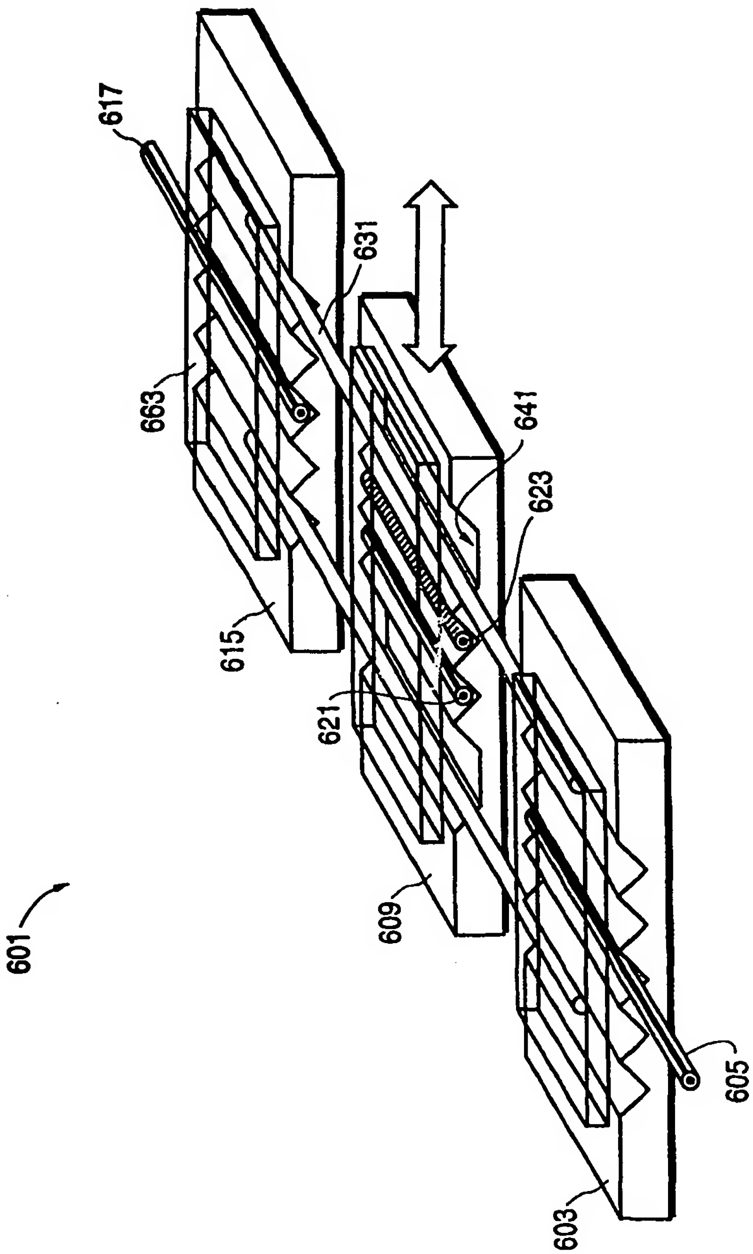

FIG.6

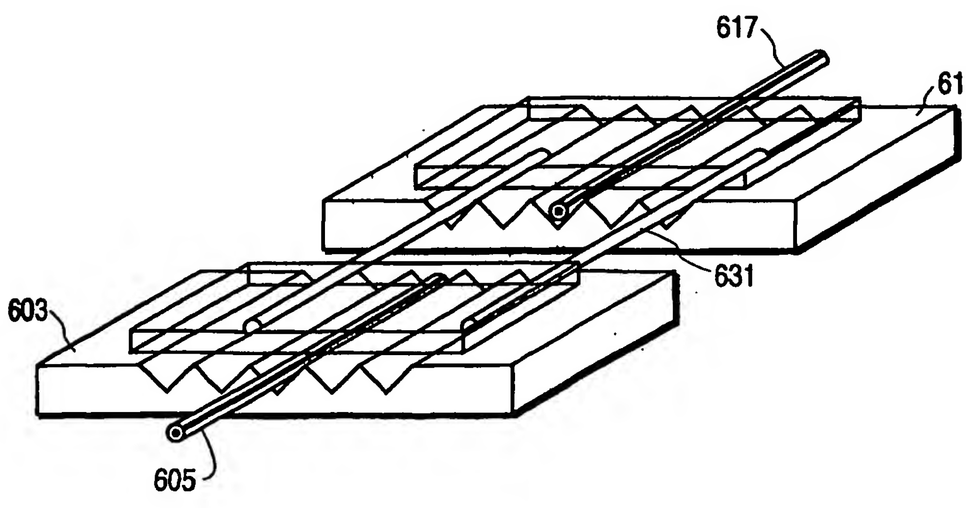

FIG.7A

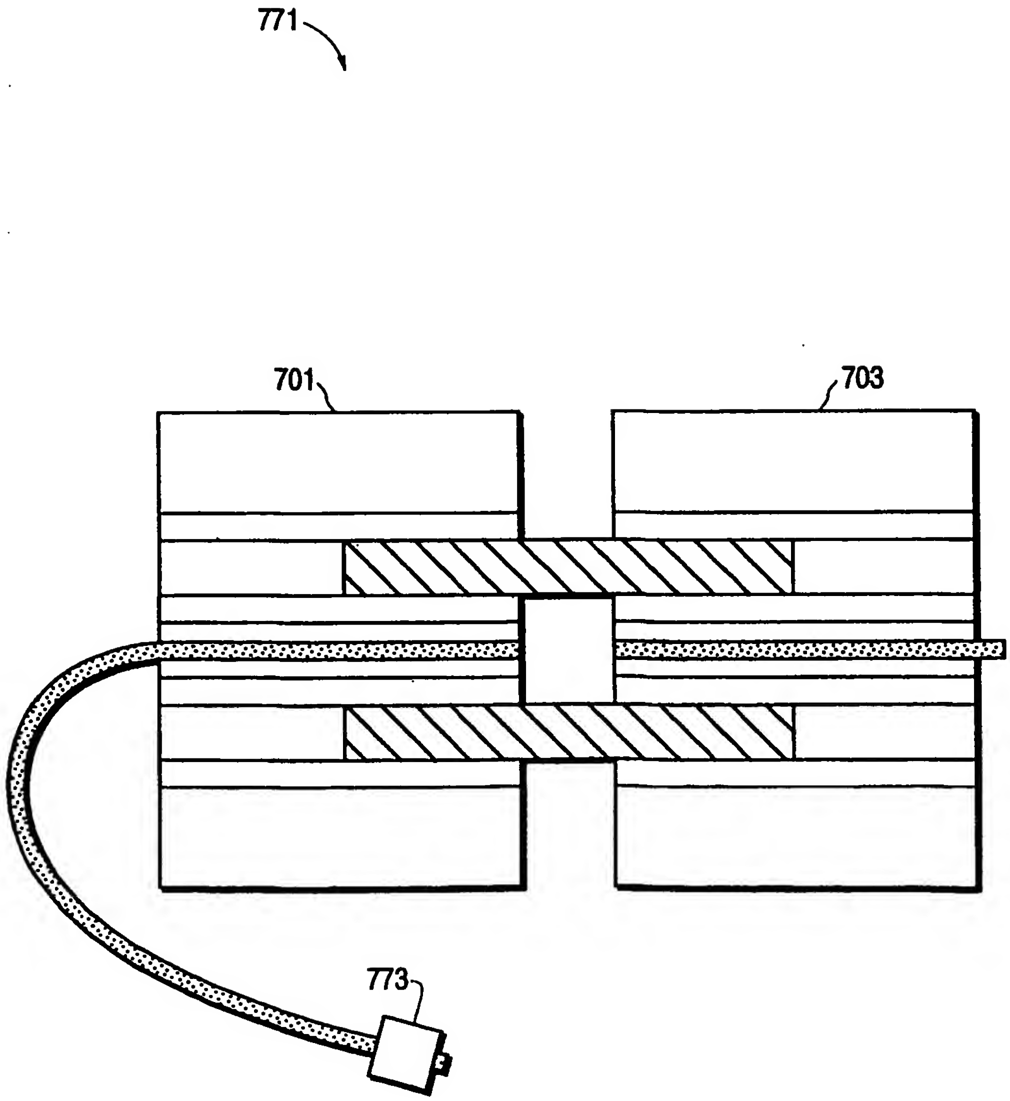

FIG.7B

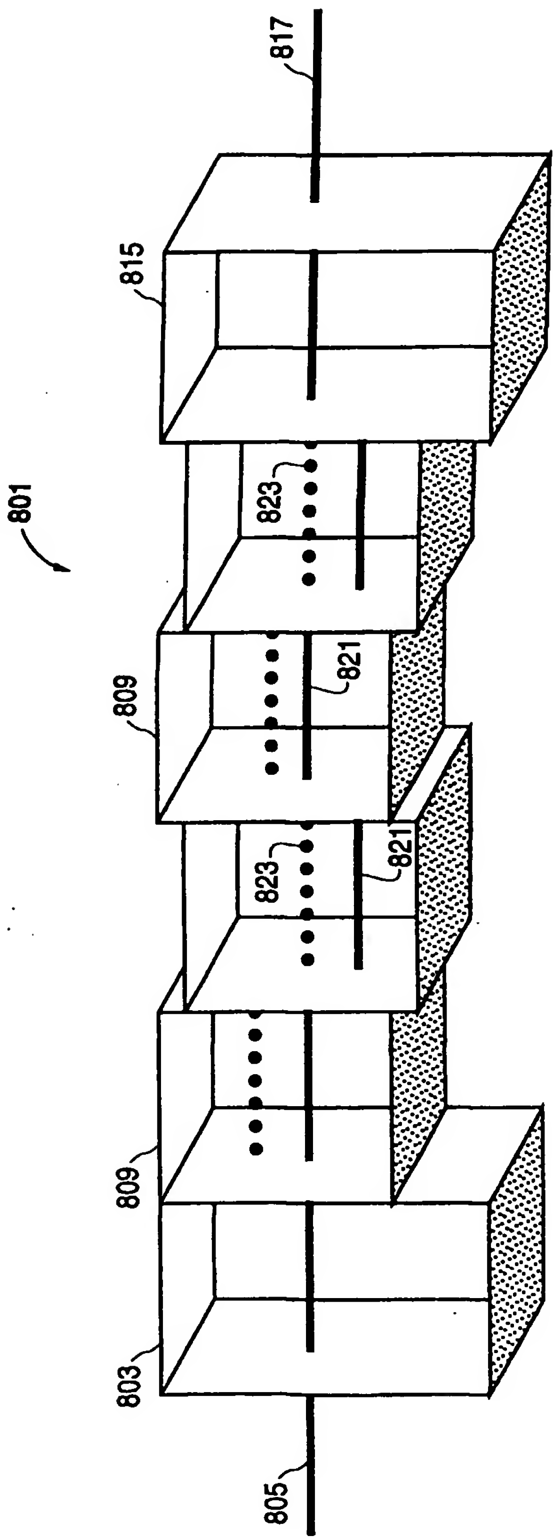

FIG.8

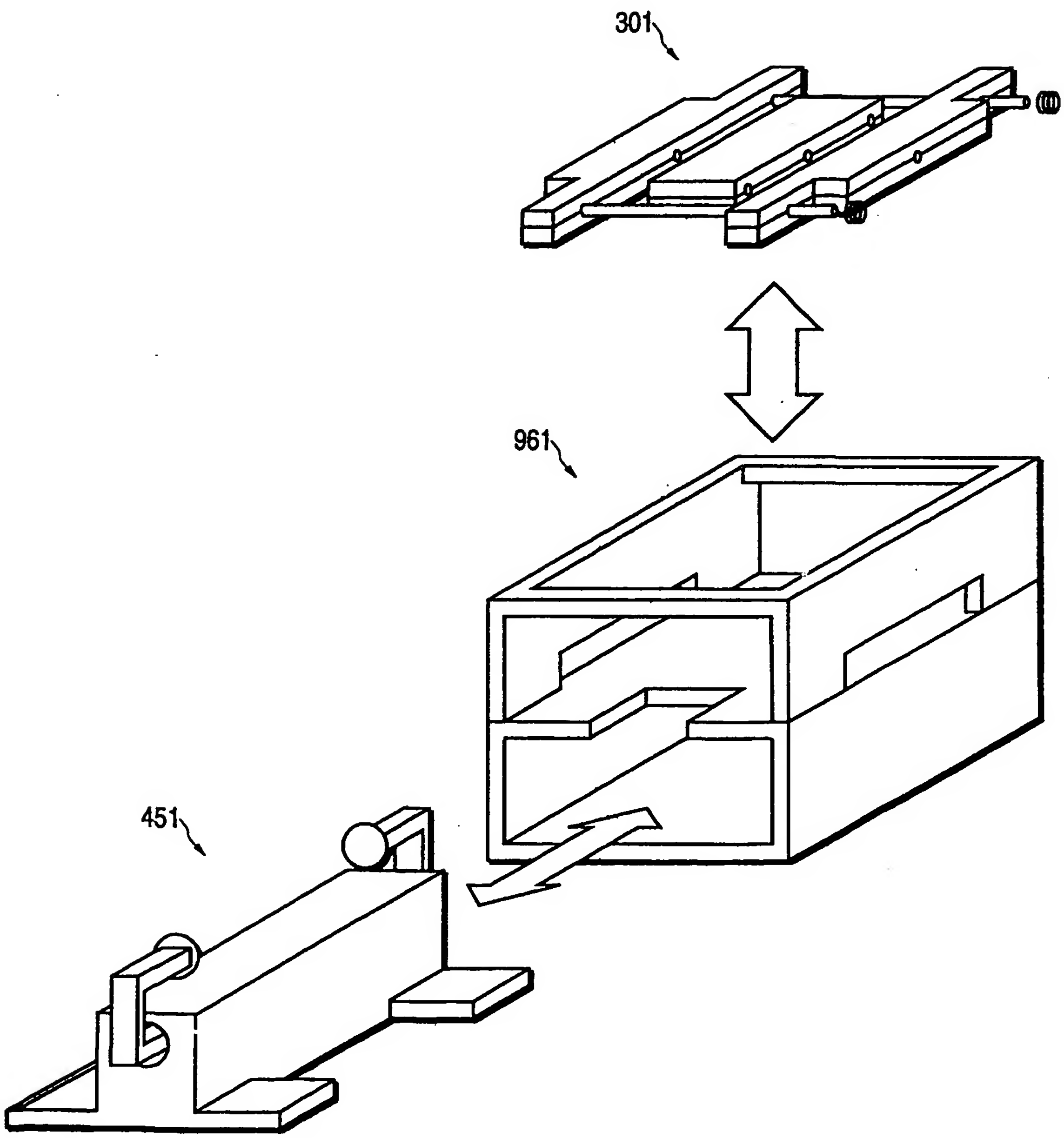

FIG.9

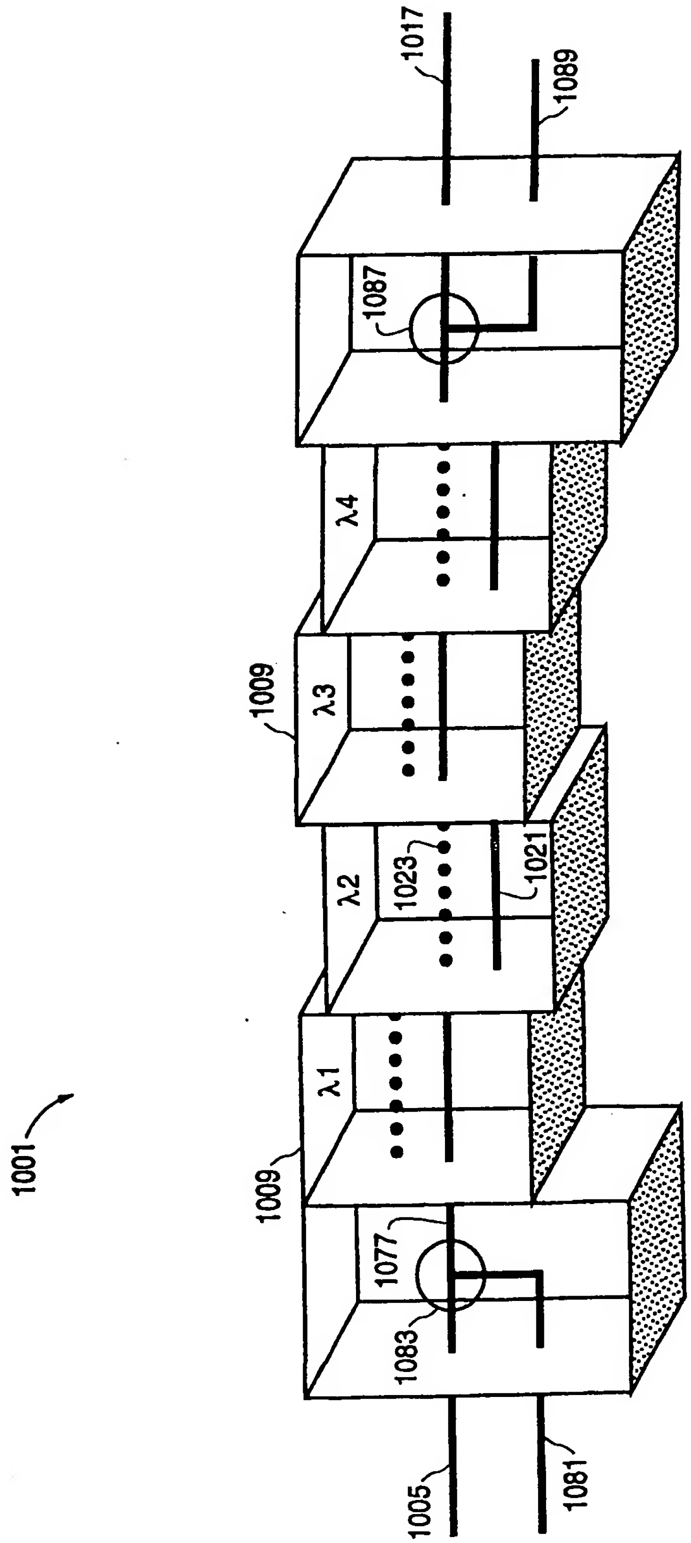
1001
1005
1081
1083
1077
1009
λ1
λ2
1023
1021
1009
λ3
λ4
1087
1017
1089

FIG.10

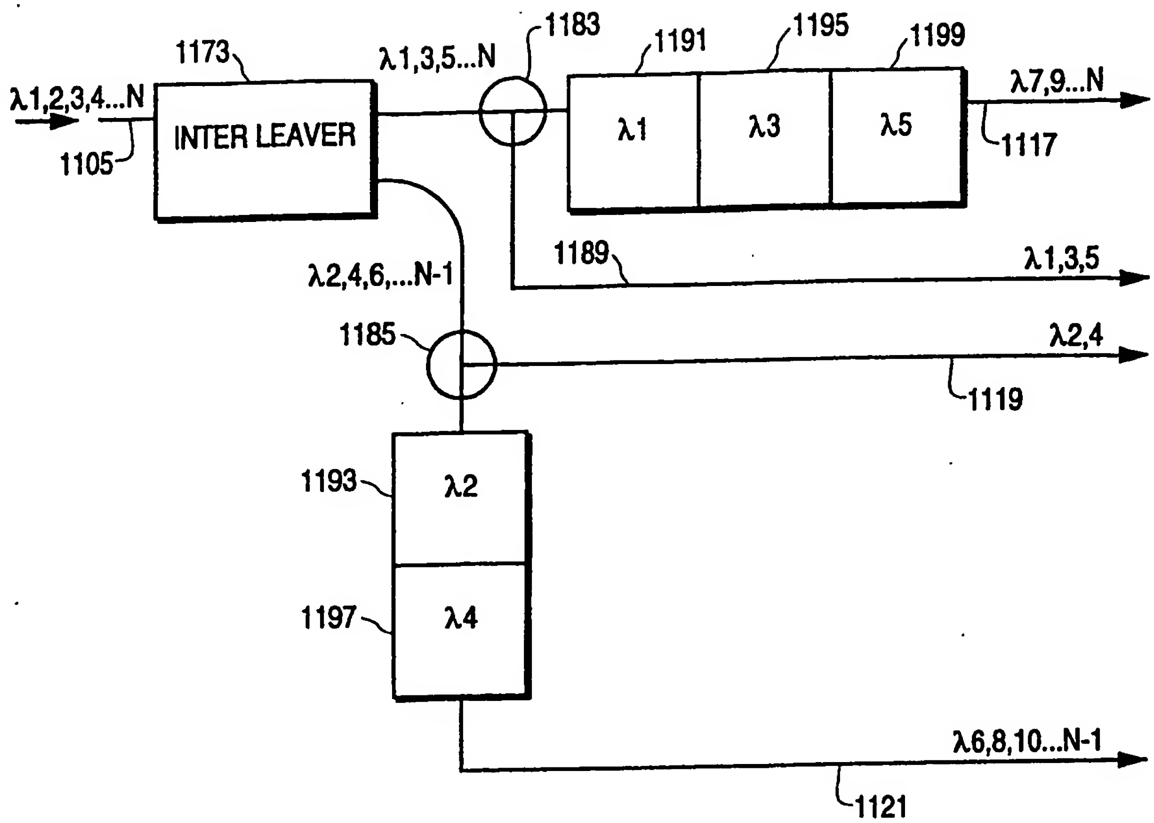
λ1,2,3,4...N
1105
1173
INTER LEAVER
λ1,3,5...N
1183
1191
1195
1199
λ1
λ3
λ5
λ7,9...N
1117
1189
λ1,3,5
λ2,4,6,...N-1
1185
λ2,4
1119
1193
λ2
1197
λ4
λ6,8,10...N-1
1121

FIG.11

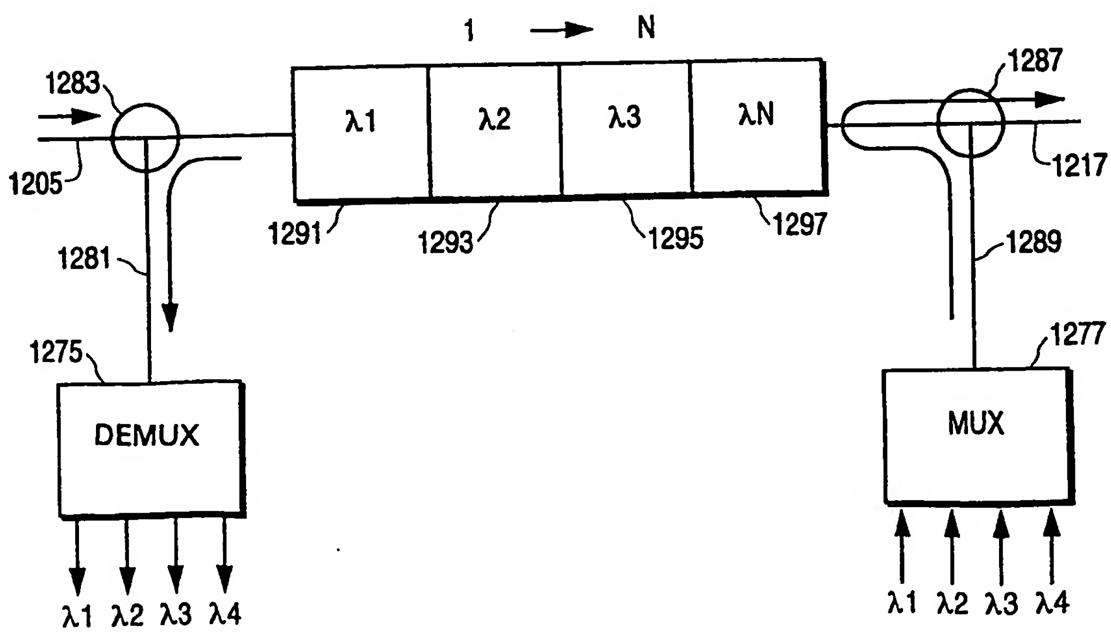
1 → N
1283
1205
λ1
λ2
λ3
λN
1287
1217
1291
1293
1295
1297
1281
1289
1275
1277
DEMUX
MUX
λ1 λ2 λ3 λ4
λ1 λ2 λ3 λ4

FIG.12

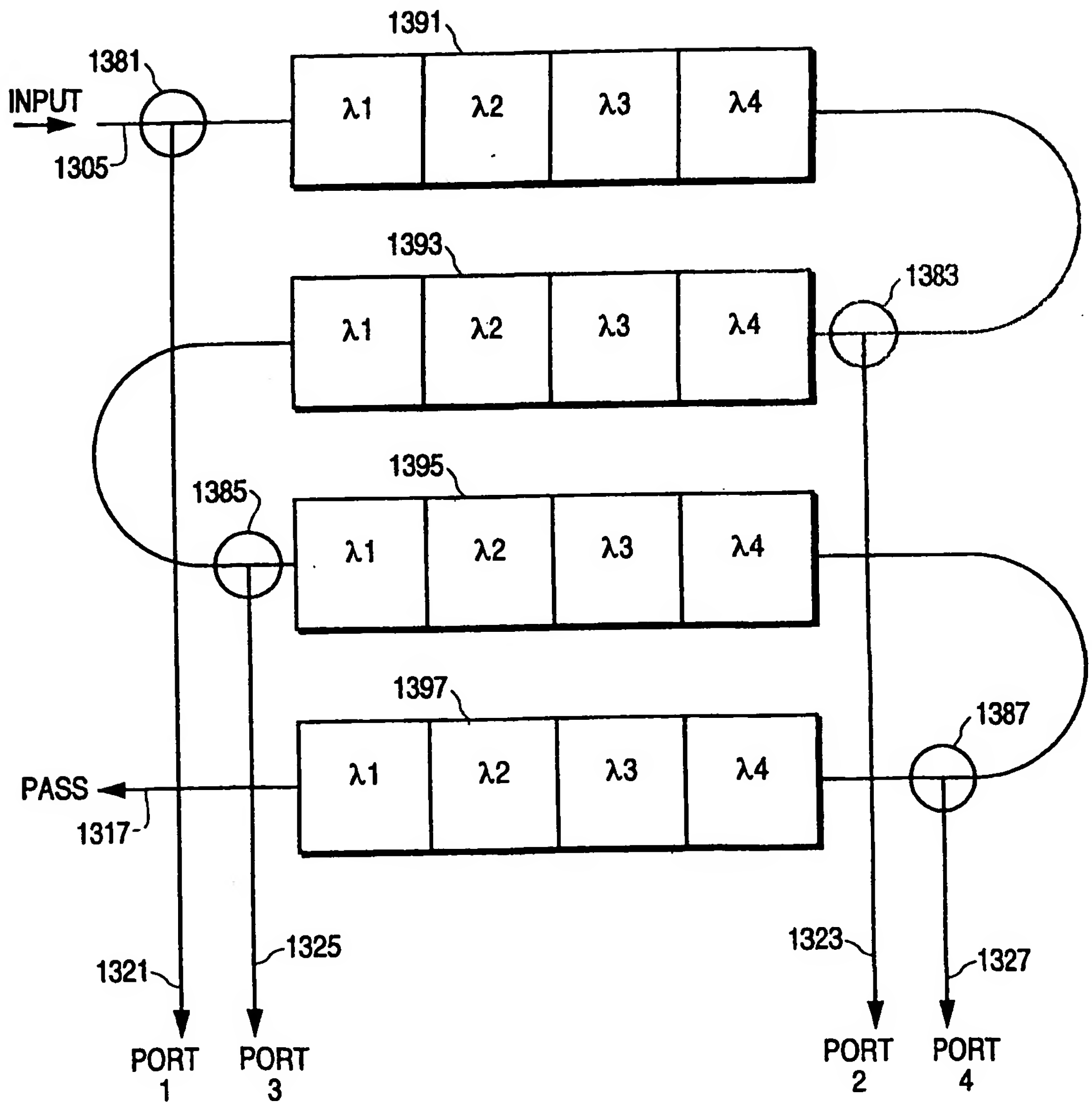
1391
1381
INPUT
1305
λ1
λ2
λ3
λ4
1393
1383
1395
1385
1397
1387
PASS
1317
1321
1325
1323
1327
PORT 1
PORT 3
PORT 2
PORT 4

FIG.13

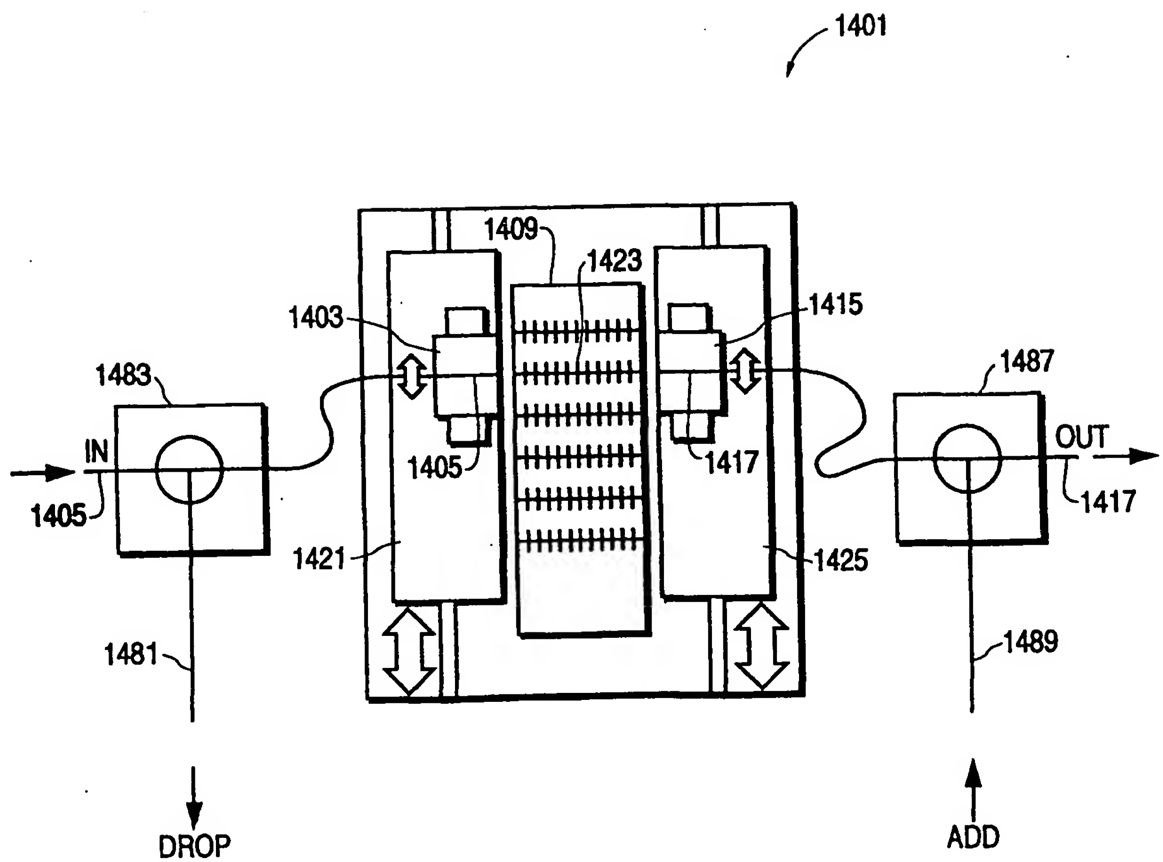
1401
1409
1423
1403
1415
1483
1487
IN
OUT
1405
1405
1417
1417
1421
1425
1481
1489
DROP
ADD

FIG.14

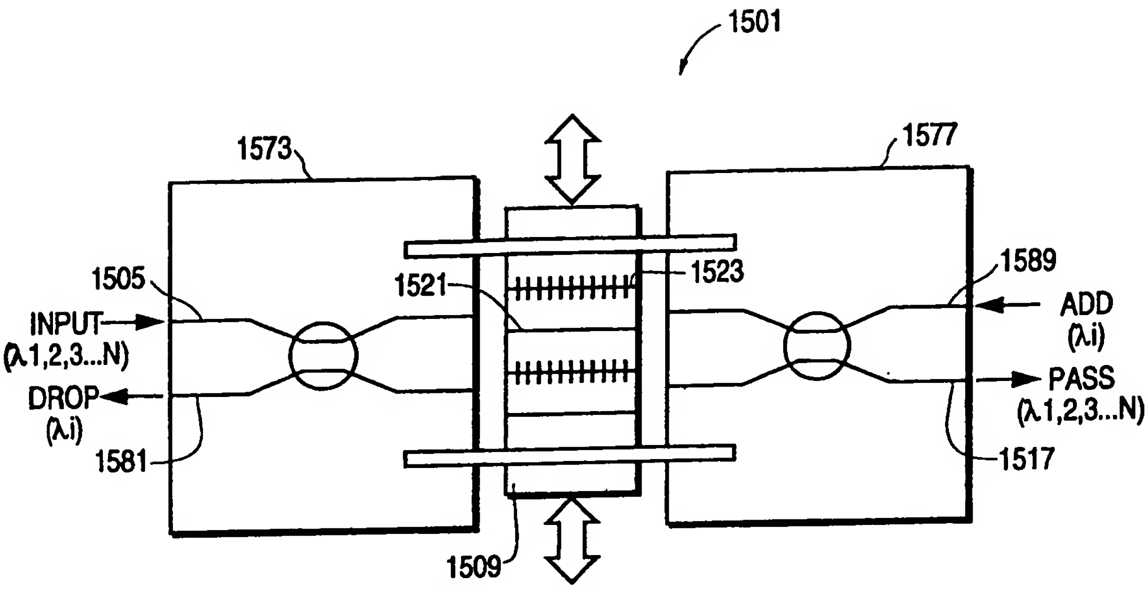
1501
1573
1577
1505
INPUT
(λ1,2,3...N)
DROP
(λi)
1581
1521
1523
1509
1589
ADD
(λi)
PASS
(λ1,2,3...N)
1517

FIG.15

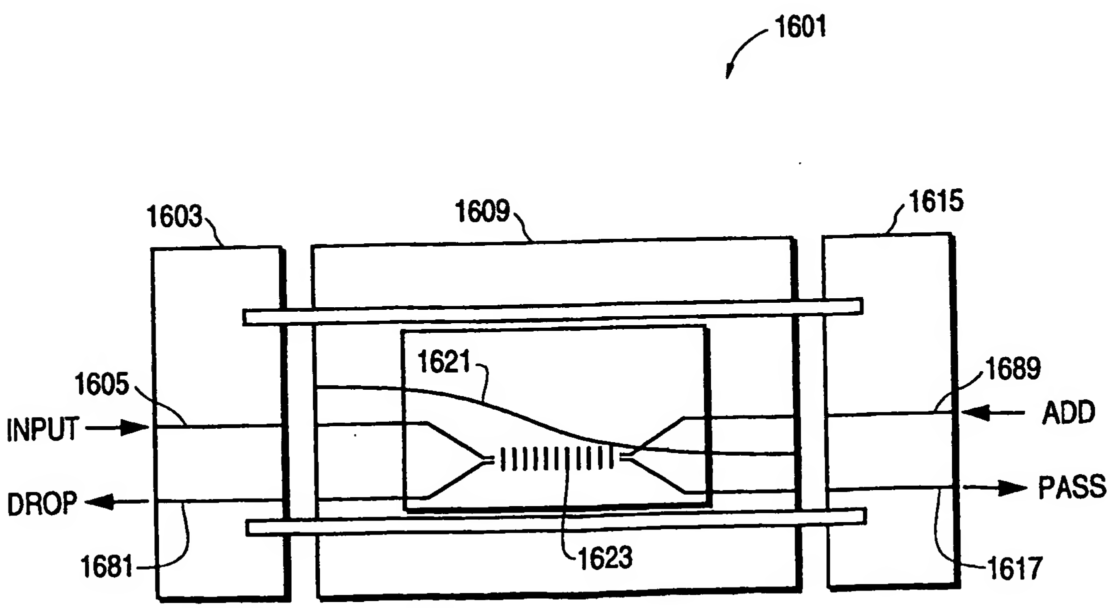
1601
1603
1609
1615
1605
INPUT
DROP
1681
1621
1623
1689
ADD
PASS
1617

FIG.16

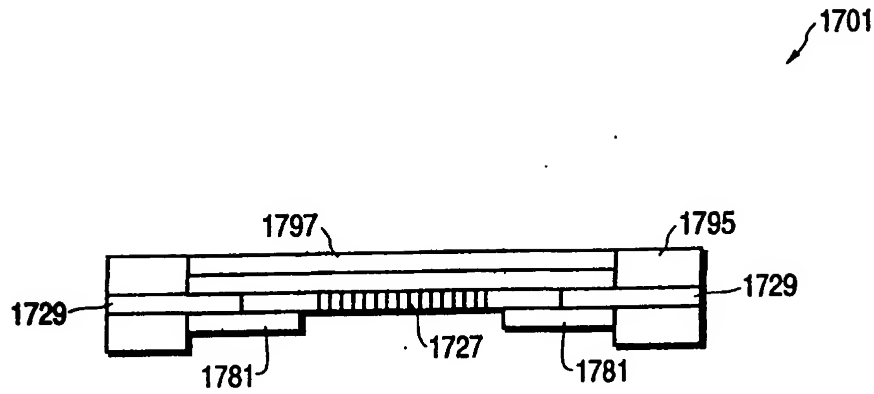

FIG.17A

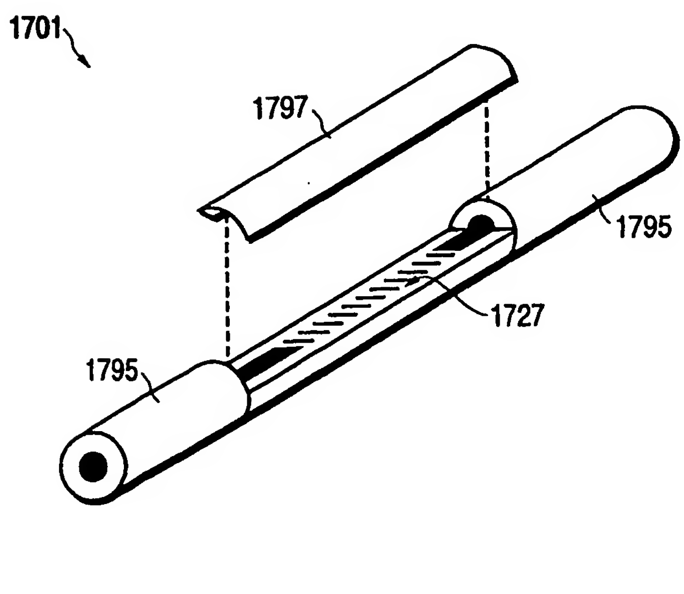

FIG.17B

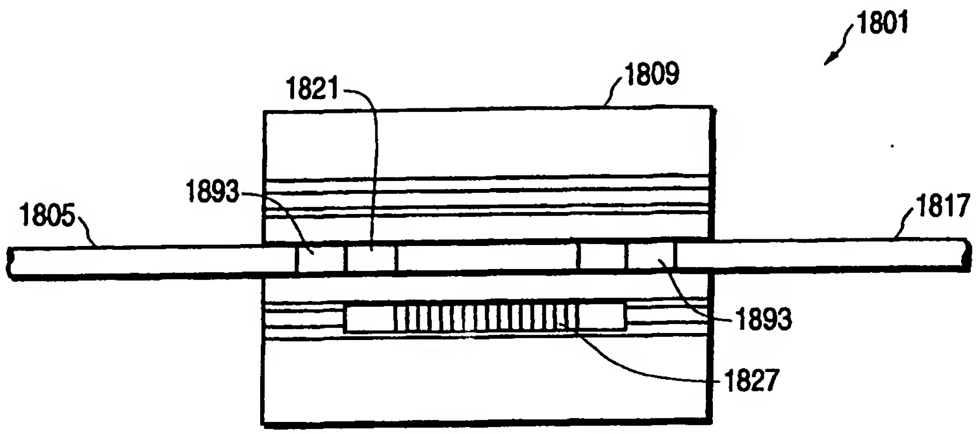

FIG.18A

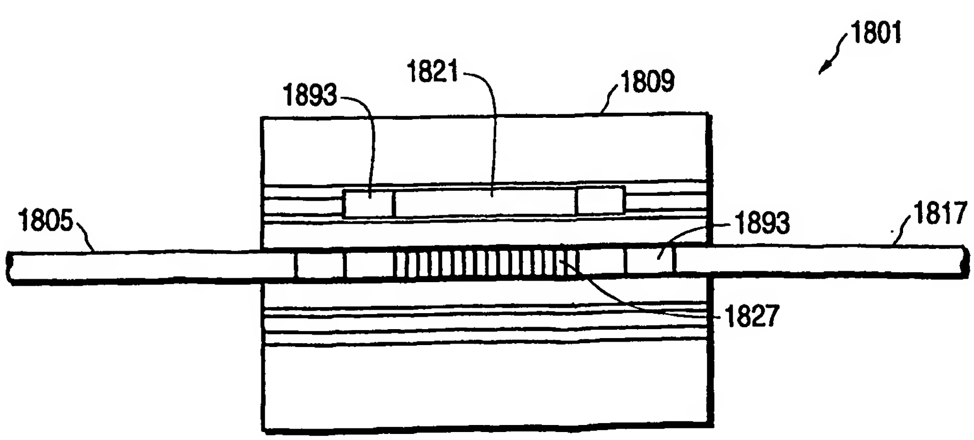

FIG.18B

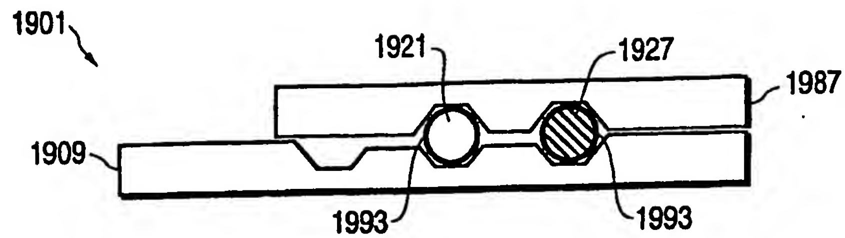

FIG.19A

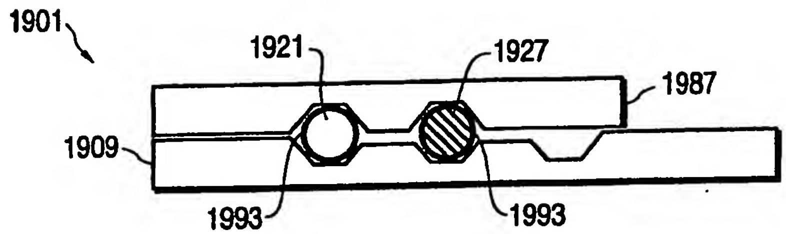

FIG.19B

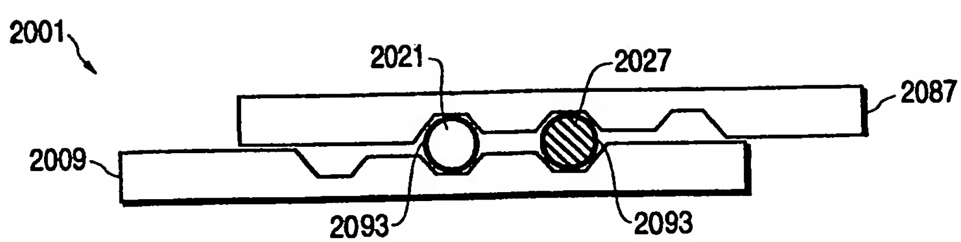

FIG.20A

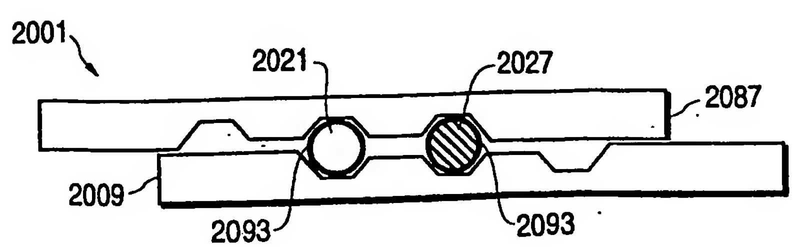

FIG.20B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/32766

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : G02B 6/34
US CL : 385/15, 16, 17, 18, 28, 31; 359/124, 127, 130

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 385/15, 16, 17, 18, 28, 31; 359/124, 127, 130

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y,E	US 6,166,838 A (LIU et al) 26 December 2000 (26.12.2000), whole document.	1-29
Y	US 4,906,064 A (CHEUNG) 06 March 1990 (06.03.1990), whole document.	1-29

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
10 January 2001 (10.01.2001)

Date of mailing of the international search report
APR 05 2001

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/32766

Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claim Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claim Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest ☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.